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LOOSE-LEAF

SURGERY

BY VARIOUS AUTHORS

EDITED BY

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IN FIVE VOLUMES
OVER 1800 ILLUSTRATIONS

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PREFACE

SURGERY is no longer "a mere mechanic art". Out of the old surgery which placed so great a stress upon technique a new surgery is being evolved, a new conception is being formed, the application of which belongs to no passing event, the future of which no one can prophesy.

Functional surgery, if one may use the term, belongs to all the future. Take, for example, abdominal diagnosis, where the mechanism of pain is a question of vast complexity, and the evaluation so essential to diagnosis. Again, the latter-day investigation of anæsthesia opens a new field and warns the surgeon that every function of the nervous system must be given detailed consideration. The study of antiseptics has linked Ehrlich's conception of chemical action with the daily technique of the operating room and extended the domain of bacteriology in the scientific treatment of wounds. It is such advances as these that we have attempted to incorporate with the portrayal of the technique of various surgical clinics. The foundation was found in Burghard's Surgery, whose various contributors in collaboration with the editors have added proved procedures from American clinics and revised the various chapters in the light of the developments in surgical practice produced by experience in war.

The loose-leaf form of the Oxford Surgery will permit the editors to present the future changes in British surgery and incorporate the best thought of the leading American clinics.

The originality and individuality obtained in these volumes will be sought rather than a colourless enumeration of operative procedures. Categorical enumeration of operations of historical interest only and procedures not demonstrated by actual experience to be of value will be avoided.

The editors wish to express to the various contributors and to those whose contributions are being prepared for future insertions the appreciation of the surgeons of America and Great Britain for their unstinted and unselfish labour during a time when they are so occupied by duties necessitated by the exigencies of war.

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CHAPTER I

INTRODUCTION

WHILST an intimate acquaintance with detail is essential for the successful practice of aseptic surgery, a thorough knowledge of the principles upon which that practice is founded is also necessary. Without such knowledge the carrying out of those details in a perfunctory and unintelligent manner, whether on the part of surgeon, nurses, or assistants, is attended with danger; for the aseptic chain is composed of many links, the breaking of any one of which may at any moment lead to disaster.

The technique of aseptic surgery as practised at the present day has gradually and steadily been evolved from contributions made by surgeons, bacteriologists, pathologists and chemists, but amid the mass of material that has accumulated the fact must not be lost sight of that the fundamental principles upon which it is based are essentially the same as those which underlay the earliest attempts to secure the healing of wounds without suppuration.

At the present time the tendency is towards simplification of methods, but there are some surgeons who feel that such simplification means the throwing away of safeguards, and that we have already advanced too far in this direction. They view with distrust the substitution of simple washing of the hands for elaborate methods of chemical disinfection, and the use of plain sterilized dressings in place of those impregnated with chemical antiseptics. Experience has shown such fears to be groundless, and this statement will, I believe, be endorsed by the great majority of operating surgeons at the present day.

Except in small matters of detail, technique may almost be said to have become standardized, and it is a technique which is based upon simple cleanliness and heat sterilization rather than upon chemical disinfection—upon belief in the germicidal power of uninjured cells rather than that of chemical antiseptics.

TERMINOLOGY

Some at least of the controversies which arise from time to time in connexion with modern surgical methods originate in nothing more important than looseness of terminology. Writers attach different meanings to words in common use, so that from this cause alone arguments arise between those who are really in entire agreement upon the principles involved. It is no longer right to speak of 'Antiseptic' and 'Aseptic' Surgery as if they represented two different and antagonistic schools of technique, for practice has become so crystallized that modifications of technique represent in the main but differences of detail, not of principle. The crude antiseptic methods of a past generation aimed less at the exclusion of micro-organisms from the wound than at their destruction in and upon it. It is the recognition of the fact that cell protoplasm is far more easily killed by chemical antiseptics than are micro-organisms which has led to the practice of what is popularly termed 'aseptic' as opposed to 'antiseptic' surgery.

In this restricted sense, dependent upon an erroneous conception of the meaning of these words, 'antiseptic surgery' represents but an evolutionary step in the development of modern surgical technique. In order to save confusion the sense in which such terms are used in this article will first be defined.

Antiseptic. Any agency which is directed to bringing about a state of asepsis is antiseptic. Heat is an antiseptic; so also is any chemical substance or solution which either destroys or prevents the growth of bacteria; any ritual of cleanliness in clothing, furniture, or manipulation designed to exclude micro-organisms from a wound is rightly termed an antiseptic method.

Aseptic. This term denotes that state or condition of a wound, an instrument, a piece of furniture, a ligature, or a fluid which results from antiseptic methods. Asepsis, therefore, has no antagonism to antisepsis, but results from and is dependent upon it.

An aseptic wound is one which heals by first intention without showing any local sign of inflammation or producing any constitutional disturbance. Such a wound is not necessarily germ-free. In 1892, W. Welch [1] drew attention to the frequency with which micro-organisms are found in aseptic wounds, and Dudgeon and Sargent [2] have made a number of observations which demonstrate the same fact. Thus in a series of forty-five cases culture tubes inoculated from a platinum loop drawn over the surface of an 'aseptic' operation wound, immediately before its closure, remained sterile only twenty-six times; yet these wounds without exception conformed to all the recognized clinical criteria of healing by primary union. In this connexion some experiments made by Schenk and Lichtenstern [3] are of interest. Having included threads of silk in a number of abdominal wounds, they with-

[1] *Trans. Amer. Phys. and Surg.*, 1892. [2] *Lancet*, Nov. 17, 1906.
[3] *Zeitschrift für Heilkunde*, xxii. 190.

drew them at various intervals and examined them bacteriologically. Out of forty-three cases thirty-nine healed by first intention, but only seven of the wounds were found to be sterile, the Staphylococcus albus being the predominant organism. Positive results were most frequently obtained on the second day, whilst a larger proportion were sterile on subsequent days. If organisms were still present after the fifth day the aseptic healing of the wound was interfered with.

It is obvious that to base the results of operations in clean cases upon a bacteriological examination and to call every wound 'infected' from which micro-organisms can be grown would give a very erroneous idea of 'operative results.' 'Aseptic' is in fact a clinical term which has no place in the bacteriologist's vocabulary. As used by the instrument-maker it merely means that the article so described can be readily cleansed and rendered aseptic.

Disinfectant. Any agent which destroys micro-organisms is a disinfectant. It is not sufficient for such an agent merely to arrest the growth of micro-organisms in order to come under this heading; it must actually destroy them. A disinfectant is, therefore, necessarily also an antiseptic, but an antiseptic is not necessarily a disinfectant. Thus many chemicals, which in concentrated form are disinfectant because they can actually destroy micro-organisms, are often used in such dilution that they do little more than hinder bacterial growth; in such strengths they cease to be disinfectant and become merely antiseptic.

Sterilization. The process of destroying all living organisms in and upon a given object is called sterilization, and any object so treated should be sterile, that is to say, it should be able to pass the most severe bacteriological tests which can be devised. It will thus be seen that aseptic and sterile are not synonymous terms. A sterile object is aseptic, but the converse is not necessarily true.

BACTERIOLOGY OF WOUND INFECTIONS

Whilst there are many micro-organisms which are capable of producing pus, it is principally the pyogenic cocci which are concerned when a clean operation wound suppurates, and of these the streptococci and the staphylococcus pyogenes aureus produce the most virulent infections. In abdominal surgery the peritoneum and the parietal wound may become infected with, in addition to these organisms, the bacillus pyocyaneus and members of the proteus and colon groups of bacilli. When infection with the last-named groups of organisms has been noted the tendency has been to the production of a low gangrenous form of inflammation rather than the type of suppuration produced by the pyogenic cocci and others. Accidental wounds, and even on rare occasions clean operation wounds, may be attacked by erysipelas and certain specific bacteria, notably the tetanus bacillus and the bacillus aerogenes capsulatus. In some cases of infected operation wounds more than one variety of organism may be present. None of the common pyogenic bacteria are spore-forming, and are therefore readily destroyed by heat and chemical disinfectants. Deductions regarding the destructibility of bacteria by various agencies, which are based upon laboratory experiments, must be received by the surgeon with considerable caution. To take as an example mercuric chloride: Streptococci taken from a culture tube, dried on a platinum needle, and immersed in a 1 in 1,000 solution of mercuric chloride have been killed in a few seconds; but in the presence of an albuminous fluid they may be so protected by the coagulum which the mercurial solution precipitates, as to endure prolonged immersion in it. Thus, a minute coagulum in the eye of a needle or in some groove in an instrument, may be a source of infection if germicidal chemicals alone are relied upon for sterilization. Even boiling water may fail to sterilize, within a reasonable time, a complicated and dirty instrument. On these grounds simplicity of construction of instruments, as well as perfect cleanliness, is necessary to ensure safety.

In all cases of wound infection a bacteriological examination ought to be made, and a thorough investigation of all the circumstances should be undertaken in order that the infection may be traced to its source, and possible repetition prevented.

The causes of suppuration in an operation wound embrace much more than the mere access of micro-organisms to it. The nature, virulence, and dose of the infecting agent, and the resistance of the patient are all factors of importance. That tissue-resistance is lowered by such conditions as the toxæmia present in diabetes and renal disease is too well known to need enlarging upon. There are doubtless many other but less obvious causes of increased susceptibility to wound infection, whether inherent and peculiar to individual patients, or temporary from causes less well understood.

Besides such general resistance the important factor of local tissue-resistance comes into play. Operative damage lowers such resistance, and therefore no account of surgical technique would be complete without pointing out its importance. Laceration and bruising of tissue by clumsy manipulation, the use of blunt instruments, rough sponging and handling, irrigation with water or antiseptic solutions, and the tying of sutures so tightly as to cause necrosis are all factors which make the tissues more vulnerable to microbic infection. Thus, the irrigation of fresh wounds with a solution of corrosive sublimate as weak as 1 in 10,000 is followed by a distinct line of superficial necrosis, demonstrable under the microscope (Halsted). Some tissues possess a greater resistance than others, which is dependent to a large extent upon blood-supply; the difference in healing power between the skin of the back and the skin of the scalp is a familiar example.

The question of rapidity of operation is very much a personal one, but it cannot be altogether ignored in discussing the causes which may contribute to suppuration. Between dramatic performances against the clock and laborious slowness there is a wide gulf fixed.

Those who have what horsemen call 'hands' can naturally operate with greater rapidity than those who possess no such dexterity; whilst one surgeon without haste or carelessness will perform a simple operation in ten minutes, another will consume half an hour over an exactly similar case. The end-result will probably be much the same in either case, but from the point of view of uninterrupted healing the more rapid operator will, other things being equal, be likely to attain the better results. The slower operation entails more manipulation of tissues, more anæsthetic, more shock, and a longer exposure of the wound. Whilst, therefore, there is a greater possibility of infection, there is at the same time a lowering of tissue-resistance both general and local.

SOURCES OF WOUND INFECTION

Whilst some of the possible sources of wound infection are undoubtedly more dangerous than others the only safe course to pursue is that which permits no relaxation of vigilance at any single point. In the war with micro-organisms, as in all other wars, contempt for the enemy may spell disaster. The following possible sources whence infection may be derived will be discussed.

(*a*) **Air-borne infection.** Whilst it cannot be denied that air-borne organisms are capable of infecting operation wounds, the importance of this source of infection has probably been exaggerated. Lister's earliest practical antiseptic methods were directed chiefly against air-borne organisms, and the carbolic spray bears witness to the importance which at that time was attached to the air as a carrier of infection. There can be little doubt that in those days the presence in hospitals of large numbers of suppurating wounds, together with lack of proper ventilation, rendered air-borne infection a more serious danger than it is at the present time.

M. H. Gordon's investigations into the bacteriology of the atmosphere of the House of Commons, published in 1906, are of great interest in this connexion. Amongst many other noteworthy observations two conclusions stand out prominently as bearing upon the potential infectivity of the air of an operating theatre, namely that (1) the chief particulate pollution was derived in part from the boots and in part from the mouths and upper respiratory passages of members; and that (2) during debates the particulate pollution from the latter source was greater than from material brought in upon the boots. Flügge and others have shown that in speaking, coughing, and sneezing germ-laden droplets may be expelled and may be carried for a distance of several feet.

Such experiments show that the air can become impregnated with micro-organisms derived from the mouth and upper respiratory passages, and also with micro-organisms brought in upon the boots. There is, therefore, good reason for the use of veils or masks, and foot-coverings, not only for those engaged in the operation but for spectators also.

Further experiments by Gordon upon contamination of the air with particulate matter derived from the scalp demonstrate the desirability of providing all who enter an operating theatre with some form of head covering. It is particularly important to cover the heads of those actually engaged in the operation on account of the ease with which dust and scurf are dislodged, especially when the heads of those leaning over the wound come into contact with one another.

In a series of twenty-five observations made by exposing Petri dishes as near to the operative field as was practicable, Dudgeon found in every instance enormous numbers of colonies. These consisted chiefly of sarcinæ and moulds, and in only one instance was a staphylococcus albus found. Masks were not worn during the operation at which these dishes were exposed. Monks[1] relates some experiments, made by exposing Petri dishes, to determine the potential infectivity of the air in the theatre of the Boston City Hospital at different times during the 24 hours. The conclusions were as follows: (1) That at no time in the 24 hours is the air free from organisms; (2) that more bacteria were found after the air had been stirred up, as after the morning cleaning. The smallest number were found between the hours of midnight and 7 a.m. (3) The vast majority of the organisms found were harmless saprophytes, though on some plates of every series staphylococcus albus and aureus were found. Streptococci were found in two instances only. (4) There was no great difference in the number of colonies obtained at different levels excepting on those plates laid upon the floor, where the number of colonies was much in excess over the other plates.

The conclusion which must be derived from the foregoing observations is that although there may be little evidence of the presence of pyogenic organisms in the air of an operating theatre, yet there is abundant proof of the possibility of air-borne infection of wounds, and full justification for the adoption of such measures of clothing and venti-

[1] *Trans. Amer. Med. Assoc.*, xxii.

lation as are capable of reducing such possibility to a minimum. This is especially important in such hospitals as have no separate organization, and no special operation theatre, for dealing with septic cases.

(*b*) **Infection from the patient.** This source of infection is well recognized; but it is possible, and even probable, that it is a more fruitful source than is commonly supposed. It is not only the skin of the operation area that must be considered, for the infective agent may gain access to the wound from the bowel in abdominal operations, and in all probability it may be transported from some remote part of the body by the blood-stream to the injured area. So far as I can discover direct proof of the blood-borne infection of operation wounds is wanting, but if a subcutaneous hæmatoma or a simple fracture can suppurate it can scarcely be doubted that an operation wound may become infected in a similar manner. The possibility of such hæmic infection is at least tacitly acknowledged in practice, for no surgeon would operate upon a non-urgent case if he were aware of the existence of a focus of suppuration anywhere in the patient's body.

Again, the resistance of patients to infection varies. We know that many aseptic wounds are not sterile, and it is only reasonable to suppose that a minute dose of an attenuated staphylococcus, which in the majority of cases would be dealt with by the tissues, might, in a patient of feeble resistance, produce suppuration.

There is yet another possible source of direct infection from the patient, which applies more particularly to abdominal, inguinal, and perineal operations in women. Organisms of the colon and proteus groups, which may be present in the urine, may contaminate the skin and so infect the wound in spite of all antiseptic precautions. Bacilluria would, therefore, contra-indicate the performance of any non-urgent operation.

(*c*) **Infection from the hands.** The surgeon, assistants, and nurses furnish undoubtedly the chief potential source of wound infection. The manner in which they may contaminate the air by clothing, skin, and saliva has already been alluded to.

There remains what, until almost the universal present-day use of rubber gloves, was probably the chief source, namely, the surgeon's hands. Innumerable methods have been devised for the disinfection of the hands, most of which are good but none of which can be regarded as completely satisfactory. Many of the tests of sterility are fallacious, such as inoculating culture tubes with snippings or scrapings from the nails and skin. It is almost impossible to prevent the introduction into the culture tube of minute quantities of the chemical antiseptics used in the disinfection of the hands, and even a trace of such chemicals may prevent the growth of organisms. It is possible, too, that a hand which was at least approximately aseptic at the commencement of an operation may, after a few minutes of sweating, be highly dangerous if brought into contact with the tissues.

Some recent experiments recorded by Hunter Robb[1] illustrate the difficulty of determining sterility in objects treated with chemical germicides. Scrapings from skin disinfected by a strict iodine method were subjected to cultural tests both before and after removal of the iodine by the use of a 10% solution of potassium iodide. Where iodine was still present upon the skin the culture tubes remained sterile in 86%; after removal of the iodine the percentage of sterile cases fell to 57.

(*d*) **Infection from materials.** All instruments, swabs, lotions, and ligatures used during an operation are potential sources of infection. Even if sterile to begin with, they may become infected during use, particularly by contact with the skin of the patient or the hand of an operator or assistant.

MEANS OF PREVENTING WOUND INFECTION

(*a*) *From the air.* In the best-equipped theatres some means of mechanical ventilation with washed or filtered air are employed. Of the 'Plenum' system, as used at St. Thomas's Hospital, the following is a brief official description:

An equable temperature is obtained without the presence in the theatres of complicated hot-water coils, and the absence of these means greater ease in maintaining the scrupulous cleanliness which is essential in a modern operating theatre; for not only is the air free from fog and dust, but there are fewer crevices where dirt may lodge than in theatres heated by water coils. The essential feature of the Plenum system is that air adequately warmed and deprived of its grosser impurities, such as soot and fog, is forced by means of a rotary fan into the rooms, from which it can only escape by a system of ducts which lead to the open air. The pure air inlets are at some distance from the floor, the air in emerging from them being given an upward direction, while the extract ducts are near the floor; the air must therefore pursue a downward course in passing out of the rooms. The inlet and outlet ducts are so placed in the theatre that the general trend of the air is from the patient toward the spectators.

There is no attempt at extraction, but since there is a slight plus pressure in all the rooms and the air will naturally find its way to the open by the outlet ducts, there is no fear that foul or foggy air will be drawn in through cracks or doors, for, even if a door is opened, the pure air will rush out but no unfiltered air will gain admission.

The rooms containing the cleaning, warming, and air-propelling

[1] *Surg., Gyn., and Obstet.*, Sept., 1913.

apparatus are situated on the floor above the theatres. The air first passes over a series of steam pipes, next through a double screen formed of coco-nut fibre continually kept moist by running water, thence over the principal heating pipes, till it reaches the fan.

The steam pipes will of course be used only in cold weather, while in summer the wet screen will somewhat cool the air which will have arrived at the fan freed from its grosser impurities and of a desired temperature.

Whilst this system prevents the entrance of a great deal of dust and dirt, it does little to minimize the possibility of aerial contamination from dust brought in by those employed in the theatre and by visitors. The use of foot-coverings, overalls, caps, and veils reduces the possibility of such contamination to a minimum. Spectators ought to be provided with such clothing, or else they should be excluded from the operation area by glass screens. The distance to which droplets of saliva can be projected points out that a coughing visitor in the auditorium may be as dangerous as an unmasked talkative operator.

(*b*) *The prevention of infection from the patient's skin* demands not only the disinfection of the skin before operation, but also the exclusion of the skin from contact with hands, instruments, and ligatures during the operation. Sterilization of the skin is probably impossible, but the number of micro-organisms can be reduced to a minimum and rendered innocuous by appropriate means. Whenever it is practicable the shaving and preliminary cleansing should be carried out on the day preceding the operation, in order to allow of the thorough drying of the skin which is essential for the success of the alcohol methods of preparation. Shaving of the skin, not only at the actual site of the incision, but also for a wide surrounding area, is necessary for almost every part of the adult body. For example, before an operation for varicose veins the whole lower limb ought to be shaved, not merely the parts around the proposed incisions. This process removes not only hair but also a good deal of surface epithelium and débris. The shaving is followed by thorough washing with ether-soap and hot water, after which the skin is allowed to dry, and the drying may be assisted by washing with alcohol or ether. In many cases it is possible and desirable for the patient to have a hot bath on the evening before the operation. The further preparation of the skin which more immediately precedes the operation may conveniently be spoken of as either wet or dry. When the *wet* method is used a compress of lint wrung out of some antiseptic solution is bandaged on and removed only immediately before the operation. In my opinion this cannot be too strongly condemned, for the sodden skin easily parts with its surface epithelium which can then scarcely be kept from contaminating the hands, the instruments, or the wound itself. The *dry* method consists in painting the previously cleansed and dry skin with concentrated alcohol, in which may be dissolved some chemical substance such as corrosive sublimate, picric acid, or iodine. Of these the last named is the most popular at the present time, and gives highly satisfactory results. It is most commonly employed as a solution of 2% iodine in rectified spirit, which is found to cause no unpleasant effects, such as blistering, even with delicate skin. Sometimes iodine vapour is given off and causes unpleasant irritation of the surgeon's eyes and nose, but this can be largely prevented by the addition of potassium iodide (2%). The same irritative effects are noticed when methylated spirit is employed in place of rectified spirit. This solution is usually painted on to the skin an hour or more before, and again immediately before, the operation. As already pointed out, it is essential for the success of the iodine-spirit method that the previously cleansed skin should have had ample time in which to become perfectly dry. In urgent cases, therefore, the shaving is done dry, and the preliminary washing is omitted. Grössich showed, by sections of skin so prepared that preliminary washing with soap and water, whilst not materially lessening the number of micro-organisms, diminishes the penetrating power of the iodine solution. Leedham Green's experiments indicate that an alcoholic solution of mercuric chloride (1 in 1,000 in 70% alcohol) penetrates the skin as deeply as the iodine solution. He holds that the percentage of alcohol is the determining factor and concludes that 70% represents the optimum strength. This observer further considers that the antiseptic effect of such alcoholic solutions depends as much, if not more, upon their hardening action as upon their bactericidal properties. It has been suggested, moreover, that the hyperæmia of the skin and subjacent tissue produced by the irritation of an alcoholic solution of iodine may be an important factor in raising the local resistance against accidental contamination with micro-organisms. A further advantage in the use of iodine solution lies in the fact that its colour indicates the extent of the area prepared, so that even in case of emergency the operator would be unlikely inadvertently to encroach upon unprepared skin. The greatest drawback to its use is, I think, that it is apt to engender habits of uncleanliness and slovenliness in dressers and nurses; it should supplement rather than replace ordinary methods of cleansing.

During the operation the skin should be excluded from the operation area by being covered with towels or gauze sheets which, as soon as the preliminary incision has been made, are turned over and clamped with special forceps to the edges of the skin. All contact with the skin can thus be avoided until the time arrives for closing the wound.

(*c*) *The hands of the operator and assistants* require the greatest care. Proper attention, especially to the nails, at all times is essential in order to keep the hands smooth and clean. Septic material should never be touched with the bare hand, nor should rectal or other septic examinations ever be conducted without the protection of rubber gloves or finger stalls. The use of strong antiseptic solutions renders the skin rough and difficult to cleanse properly, but in this respect some skins are more vulnerable than others. Of the many different rituals for rendering the hands aseptic, none has been shown to excel that of thorough washing with ether-soap under a stream of hot water, especially when this ablution is followed by rubbing with methylated spirit.

However well it may have been cleansed, the bare hand can never be regarded as sterile, and should therefore never be brought into contact with the wound, or with ligatures. The use of rubber gloves, sterilized by boiling or by dry heat, is now almost universal; but those who do not employ them claim equal safety by the rigid avoidance of touching the wound with the fingers or any part of an instrument or ligature which will come into contact with the wound.

In order that rubber gloves may be safe, they must be free from holes, otherwise there is a danger of contaminating the wound with sweat forced through such openings by the movements of the hand. For the same reason the gauntlet should fit the wrist closely, otherwise germ-laden sweat may escape and drip into the wound or on to the towels. This danger is often mentioned by those who are opposed to the use of gloves, but it is one which has possibly been overrated. Some years ago C. Harrington[1] made a few experiments concerning the infectivity of sweat. Well cleaned and so far as is possible sterilized forearms and hands were encased in sterile glass cylinders heated by appropriate means; in no single instance could a bacterial growth be obtained from the sweat so produced. Moreover, injections of this sweat into animals, whether subcutaneously, intravenously, or intraperitoneally, were quite devoid of results.

It should be unnecessary to add that the glove should not be regarded as a substitute for cleanliness of the hands, which should be prepared with the same scrupulous care as if gloves were not to be worn. Perhaps the greatest use of the rubber glove in aseptic work is its systematic employment in septic cases; hands thus shielded from contamination are more easily rendered aseptic when the time comes for dealing with clean cases. The argument against the use of gloves that they interfere with sensitiveness and delicacy of touch has not survived the test of experience. It is purely a matter of practice, for those who habitually

[1] *Trans. Amer. Med. Assoc.*, xxii.

wear gloves for all cases feel as strange without them as the unpractised surgeon would feel when using them for the first time.

The forearms must be cleansed with the same care as the hands, for they may at any time be accidentally brought into contact with sterile objects. Some surgeons prefer to have the forearms covered, and for this reason use overalls with long sleeves, the wristlets of which can be tucked inside the glove gauntlet; others use separate sleeves made of stockingette.

(*d*) In speaking of the foregoing sources of infection, namely the air, skin, and hands, only the terms clean and aseptic could rightly be employed. When instruments, dressings, and ligatures are being considered the term sterile must be used, for all these can and ought to be rendered sterile and capable of passing the most rigorous bacteriological tests. Nothing, therefore, which cannot be sterilized easily and certainly should be employed, and for this reason marine sponges, amongst other materials, have been abandoned by all but a very small minority of surgeons.

Instruments. Sterilization by superheated steam, and even by dry heat, is occasionally employed, but sterilization by boiling water is the plan most commonly adopted, and provided that an instrument is perfectly clean and so constructed that the boiling water can come into contact with every part of it, this is a perfectly reliable method. Spencer Wells artery forceps and other instruments with corrugated jaws require special attention, and should always be unclamped before being boiled, otherwise any chance organisms enclosed within the jaws may escape destruction. Five minutes' boiling amply suffices for the destruction of all non-spore-bearing organisms. Cutting instruments are liable to be blunted by boiling, so that it is the practice of many surgeons to trust to their immersion in pure carbolic acid or even alcohol. For this method to be safe it is essential that the instrument to be so disinfected should be perfectly smooth and clean, so that the solution can come into actual contact with every part of it.

Certain instruments, such as the cystoscope, which cannot be boiled without damage may be sterilized by formalin vapour in special apparatus. Such an apparatus comprises a glass container, which is fitted with a nickel-plated cover and a perforated metal plate, for holding either catheters or cystoscope; a nickel-plated metal stand; a glass chamber for the development of formaldehyde gas which is generated by placing a vial of 'Autan' powder in the vessel and adding 8 c.c. of water (Allen and Hanburys).

Dressings, swabs, towels, and overalls are usually sterilized by superheated steam in an autoclave. The method in use at St. Thomas's

Hospital, which may be taken as typical of the methods commonly applied at the present day, is as follows: The materials are packed in cylindrical tins, the lids of which are large enough to fit loosely over their open ends. It is of the utmost importance that the contents should not be packed tightly, lest the penetration of the steam to every part should be impeded. The open tins, each standing upon its own lid, are placed in a Manlove and Alliott steam sterilizer which has previously been heated to prevent condensation. These tins are mainly used for dressings and swabs. Larger square tins with hinged lids are employed for towels and overalls. The actual process of sterilization comprises first the production of a vacuum, which is maintained for ten minutes. This encourages the penetration of the steam, which is next admitted under pressure for twenty minutes, and at the end of this time the vacuum is again created for the purpose of drying the sterilized materials. The pressure used is between 15 and 20 lbs. The average temperature attained is therefore about 255° F.

When the process has been completed the attendant opens the sterilizer and at once puts on the overall and rubber gloves which have previously been placed therein for this purpose. He then takes out a tin, places it upon a carbolized table, and puts on the lid.

From time to time, and without previous notice having been given, a tin is sent to the pathological laboratory for bacteriological examination, and the results have been found to be uniformly satisfactory. The texture of the dressings is not found to be undesirably altered by the sterilizing process described above, whilst the towels and overalls last as long as can reasonably be expected.

Ligature and suture materials. It is customary to speak of these materials as absorbable and non-absorbable, the former class including catgut, kangaroo tendon, and other animal substances; and the latter silk, linen thread, celluloid thread, and silkworm-gut. To some extent absorbable and non-absorbable are but relative terms, for whilst there is some evidence to show that fine silk may ultimately be absorbed, it is also certain that the coarser sizes of chemically hardened catgut may resist absorption for many months. The great difference between silk and catgut is that the former can be rendered sterile with absolute certainty by boiling, whereas catgut cannot be so sterilized without damage. A few cases of post-operative tetanus have been ascribed to its use, but improved methods of sterilization have removed this objection, and now it is in very general use.

In open wounds treated by Dakin's solution the possibility of rapid absorption should be borne in mind and the heavier varieties used. This also applies to silk and all animal sutures.

Secondary hæmorrhage has occurred a number of times from this early absorption.

Linen thread saturated with paraffin in the form of Pagenstecher's linen is popular as a skin suture.

In septic cases its advantages are more obvious, for in such silk is liable to give rise to persistent sinuses.

The term irritating as applied to a buried suture of silk or silkworm-gut is a misnomer. Such sutures are 'irritating' only when they are septic or when, owing to impregnation with strong antiseptics, they cause necrosis of the surrounding tissue. However prepared, a suture which is sterile to begin with, may become septic by the time it is buried from careless handling, from contact with skin or from some other surgically unclean source.

Silk is prepared in the following manner. It is first disposed in loosely arranged skeins, and boiled for ten minutes on three successive days. It may conveniently be stained with some aniline dye, such as methyl violet, to make it more easily visible. It is then wound loosely upon glass reels or slats, boiled again, and preserved in 1 in 20 carbolic; if undyed it may be preserved in alcohol. It should be boiled or immersed in sterilized saline immediately before use in order to remove the chemical.

Numerous methods are employed in the preparation of catgut. Raw catgut must be washed in ether to remove the grease, after which it has to be hardened in order to ensure its not being absorbed too soon, and finally it must be sterilized. It is difficult to be at all sure how long any given specimen will resist absorption. Bichromate of potash is the agent most commonly employed for the hardening process, a solution of from 1 in 1,000 to 1 in 100 being used according to the degree of hardening desired. In this solution the gut is immersed for about an hour. The sterilization is afterwards effected either by immersion in spirit-iodine or pure carbolic acid or by boiling in alcohol or xylol under pressure. Satisfactory results may be obtained by a large number of different methods. It must be remembered that the finer the gut the more certainly it can be sterilized.

The place of chemicals in surgery. It is now so generally conceded that chemical antiseptics must not be brought into contact with living tissue that it would appear superfluous to discuss this aspect of the subject. Chemicals destroy cell protoplasm more easily than they can kill micro-organisms, whilst the living cells and body fluids of a fresh clean wound are germicidal, and are capable of dealing with such small numbers of micro-organisms as may elude even the most rigid antiseptic precautions. Lockwood states that biniodide of mercury is less open to the objection of damaging the tissues than corrosive sublimate or carbolic acid; that 1 in 4,000 biniodide lotion merely swells the red cells and does not crenate them like 6% saline; and, further, that even by microscopical examination he was unable to tell the difference between portions of muscle and fat taken from a wound before and after irrigation with this lotion. If this is so it is difficult to understand what antiseptic value the lotion can possess.

Bacteriological considerations therefore combine with practical experience in condemning the irrigation of clean wounds with chemical antiseptics. The same considerations apply also to the use of sterilized water, which exerts a destructive action upon living cells through the osmotic processes set up. Sterilized physiological salt solution is free from these disadvantages, and is therefore the only fluid which should be brought into contact with clean wounds. All irrigation is open to the objection that protective fluids are washed away, and it should be employed only when there is some special object to attain, such as hæmostasis or the washing away of blood in situations where sponging cannot be employed, as in cerebral and spinal operations.

Briefly, chemical antiseptics find their proper place in modern surgical technique to be limited to the following uses: (*a*) As disinfectants for the sterilization of such articles as, from their nature or construction, cannot be submitted to the more certain process of sterilization by heat; (*b*) as antiseptics incorporated in dressings for the reception of exudate from aseptic wounds when it has been thought desirable to provide drainage, or when leakage is expected. Such dressings are wholly unnecessary for aseptic wounds which have been completely closed; (*c*) in the preparation of skin and mucous membranes preliminary to operation; (*d*) in the treatment of infected wounds.

Drainage. With improvements in technique the necessity for drainage in aseptic wounds has practically disappeared. Many surgeons, however, think it desirable to provide an exit for the albuminous fluids which are apt to accumulate in a large 'dead space,' such as that resulting from an extensive mammary extirpation. The principle upon which drainage is so employed rests upon the possibility of any organisms which may be present being able so to thrive upon the dead material as to become too numerous or powerful for the living tissue around to cope with successfully. It may be added that such exudation is more abundant after irrigation of a wound with even weak antiseptics; it is also more abundant in the case of a limb the tissues of which have been temporarily rendered bloodless by means of a tourniquet. 'Dead spaces', however, can usually be obliterated by deep suturing or by properly applied dressings, so as to render drainage even on these grounds rarely necessary.

The use of a drainage tube invites subsequent infection along its track. The drainage of a psoas abscess, for instance, is almost inevitably sooner or later followed by pyococcal infection of the cavity. Even in cases where drainage is thought desirable from the point of view of preventing accumulation in a 'dead space,' the employment of a glass tube for 24 to 48 hours is all that is necessary, and such a tube is best inserted between two stitches in such a manner that on its withdrawal the lips of the wound come naturally together. If done in this way the chances of subsequent infection from without are reduced to a minimum.

The drainage of infected wounds is a different matter. Whilst tubes, usually of rubber, are most commonly employed, the use of strips of gauze is often favoured. A piece of thin sheet rubber wrapped round the gauze strip (the cigarette drain of Mikulicz) facilitates its removal. With all forms, but particularly with gauze, great care is necessary lest the drain defeats its own object by preventing the escape of discharge.

Gauze may be employed in the treatment of septic wounds in a different manner. The whole wound, including all recesses and pockets, is packed with gauze, which is therefore everywhere in contact with its walls. Provided that the temperature does not rise, and the wound is not painful, such a packing can be left in for two or three days, when it can be removed without pain and the cavity will have become lined throughout with granulations.

THE REQUIREMENTS OF AN OPERATING THEATRE

Design. In a hospital it is desirable that each surgeon should have his own theatre, which should be in close proximity to his wards. The theatre block should contain certain rooms opening out of or communicating with the operating room, some of which are indispensable whilst the others are eminently desirable. These accessory rooms comprise: (1) A dressing room for the surgeon and assistants, where preliminary washing should be performed, and the sterilized garments put on. A similar room is necessary for the nurses. (2) An anæsthetising room, which should contain all the anæsthetist's apparatus. It is desirable that the patient should, whenever practicable, be placed in position for the operation in this room, and that the blankets and macintoshes should be arranged before he is wheeled into the theatre so as to avoid contaminating the air with fluff and dust from blankets and clothing. (3) A recovery room in which the patient can be placed after leaving the theatre and before being taken back to the ward. (4) A sterilizing room containing the large autoclave, and perhaps also smaller apparatus as well for sterilizing instruments and for preparing saline solution.

While the interests of asepsis have brought about the wellnigh universal use of white walls and floors, often of tile, many operators now prefer that the lower three-fourths of the walls and the floors should be of some darker colour, preferably a steel grey, so that the brilliant reflection from the walls will be less tiring to the eyes. Sufficient light is secured by the reflection from the ceiling. This darkening of the walls, which may be carried to the other objects in the room, is undoubtedly of great benefit reflexly in clarifying the minutiæ of the operative field. The ventilation should be ample and there should be means available for preserving an equable temperature.

Heating. The regulation of the heat in a theatre is easily carried out when some system of artificial ventilation such as that described is employed. When such is not the case steam-pipes or electric radiators may be used, but they have the disadvantages of taking up space and furnishing an undesirable addition to the contents of the theatre which requires to be kept clean and dustless. Electric radiators have not the same heating power as steam-pipes but they have the advantage, which steam-pipes do not possess, of cooling rapidly when the supply is turned off. Opinions differ as to the temperature at which the atmosphere of an operating room should be maintained, but this is chiefly when the surgeon's personal comfort rather than the patient's welfare is taken as the criterion. The recognition of the fact that maintenance of body temperature is important amongst the measures to be adopted for prevention of shock, points to the necessity of keeping up the temperature of the theatre to a point which some operators find uncomfortable. It should not be allowed to fall below 65° F. But inasmuch as the actual temperature is not the only criterion of comfort, proper ventilation, together with measures for keeping steam out of the theatre, have to be adopted.

Lighting. Daylight is usually preferred to artificial light, and the properly designed theatre provides for both. A roof light facing north may be supplemented by light derived from the sides when circumstances permit. But the greater the window area, the more difficult will be the problem of maintaining the proper temperature of the room.

Artificial light presents difficulties to overcome which many excellent devices have been introduced. It need hardly be said that electric light is the only form which need be discussed. The overhead disposition of the lights, even when these are so arranged as not to throw shadows, is not ideal because of the danger of dust. In some theatres light is thrown upon the table by reflectors so placed as to avoid the production of shadows from the surgeon and assistants whatever may be their position, and some such system as this is perhaps the best. In addition to the main lighting a complete installation is required for headlamps, cystoscopes and so on.

Spectators. The accommodation of students and other spectators is always a matter of difficulty, and one which has yet to be satisfactorily solved. Theoretically, those not directly engaged should either be provided with complete outfits of overalls, caps, veils, and boot coverings, or they should be separated by a glass screen from the main body of the theatre. In either case it is difficult for more than a few to see much of what is going on.

Fittings. It is hardly necessary to state that the walls and floor of the theatre should be of material which is non-absorbent and easily cleaned, and that no cornices or recesses in which dust might lodge should be allowed. All shelves and sinks should be fixed sufficiently far from the walls to allow of being cleaned on all sides. To permit of easy flushing, the floor should be built with a slight inclination towards an open channel which has a single trap where it passes out of the theatre. All 'dusting' must be done with damp cloths. Taps should be of the simplest description. Those which are operated by elbow levers or pedals are generally, in my experience, useless. The somewhat complicated mechanism of the latter easily gets out of order, whilst the former engender a false sense of cleanliness since the elbows, whether bare or clothed, should be as clean as the hands. Complicated mechanisms for regulating the temperature of the water rarely work in practice. The simplest, cheapest, and most satisfactory arrangement is a simple Y-shaped metal tube connecting the hot and cold taps, and arched over the sink sufficiently high to allow of the whole forearm being washed under a stream of running water, the force and temperature of which can be easily regulated by the two taps. This can be done before washing, and a nurse can be told off to turn off the taps when economy of water has to be considered. Washing should always be done in running water over a sink; hand basins for this purpose have no place in a properly equipped theatre. Sterilizers for instruments ought to be as near to the operation area as is practicable. The escape of steam into the air of the theatre can be prevented by having the sterilizer placed beneath a cowl; or the whole process can be carried out in an adjoining room, and the sterilized instruments passed into the theatre through a serving-hatch.

Furniture. The best form of operating table is that which provides for easy adjustments in all necessary directions with the simplest mechanism, and with the minimum of disturbance to the patient. It should be firm and rigid, and capable of being raised and lowered to suit the convenience of different operators. It should also be readily adjustable for special positions like the 'Trendelenburg' and 'lithotomy' positions, and be fitted with removable special parts such as head-rests, arm-rests, and so on. It should be capable of being easily cleaned in every part. The heating may be carried out by hot water or by electric glow-lamps; in either case the greatest care has to be taken to prevent burning the patient.

The rest of the furniture should be of the simplest possible description. Glass-topped trolley-tables are commonly used for placing instruments and other apparatus upon. The two-decked table is a source of danger to be guarded against, for a person stooping to reach the lower shelf may touch and contaminate articles upon the upper shelf. Stools may have to be provided for anæsthetists, and for those surgeons who prefer to be seated whilst operating.

ISOLATION OF SEPTIC CASES

It has, of course, long been recognized that erysipelas and pyæmia must not be treated in a general surgical ward. In an ideal hospital all septic cases would be excluded from the ward in which clean cases are being treated, nor would any septic case be operated upon in the same theatre as the clean cases. In a general hospital this arrangement is unfortunately impracticable, at any rate in its entirety. At St. Thomas's Hospital, where a certain number of beds are available in the isolation block, any septic cases of severe type which may arise in the surgical wards are at once transferred. Moreover, no cases of cellulitis, acute abscess (other than abdominal), or gangrene are admitted to the general wards, or operated upon in the general theatres; they are dealt with in a separate theatre in the isolation block and are under the charge of special house officers and nurses.

ORGANIZATION

Inferior methods efficiently carried out may give better results than the best methods carelessly or ignorantly applied. It is not sufficient for a hospital or a nursing home to possess the latest luxuries in design, construction, and furnishing of its theatres. The intelligent and painstaking co-operation of the whole theatre staff is essential if the best results are to be obtained. The surgeon cannot personally superintend the carrying out of all details, although he may have given the most minute instructions. He must naturally, however energetic and precise himself, always be to some extent at the mercy of his subordinates and assistants, though naturally the best organizer and disciplinarian will in the long run obtain the best work. The surgeon's duty does not begin and end with playing his own part as perfectly as he can; he is both actor and manager in his theatre, and he should make it his business to be thoroughly acquainted with all the details of the particular technique carried out in his theatre, as well as with the part expected to be played by his staff. He would, if possible, select his assistants and nurses himself, and see that they have the necessary knowledge of his methods as well as of the general principles of aseptic surgery. Unfortunately such an ideal arrangement is not practicable in the case of a teaching hospital. The selection of house surgeons and dressers may not be within the province of the surgeon with whom they have to work, and the appointment of sisters and nurses is usually outside his sphere also. He therefore has to work periodically with new scratch teams, and changes are often made just as the team is beginning to work together efficiently. Such a handicap is inseparable from a teaching hospital; it has to be recognized as such, and special precautions have to be taken to minimize its ill effects. But whilst the more immediate and obvious result of this system is to increase the work and the anxieties of the surgeon, and probably also to produce an increase in the number of cases which suppurate, the larger question must not be lost sight of, namely, that a constant supply of properly trained and efficient men and women is being sent out into the world. Indeed, the surgeon's duty of teaching and training is second only to the duty towards the patients under his care.

At St. Thomas's the house surgeons are appointed for a period of six months, during which time they work for three months each with two surgeons. Each surgeon, therefore, has a new man every three months; the alternate changes bring him an untrained man and a man familiar with the methods of another surgeon. This arrangement is better for the house surgeon than for his chief, but on the whole it works very well. The dressers take duty for six months. At the operations the house surgeon acts as chief assistant, and the dresser in charge of the case is the second assistant, the other dressers being ready to assist as required. Each pair of theatres is in the charge of a sister with a staff of nurses for whose training she is responsible. During the operations one nurse is told off to fetch and carry, to attend to taps and so on, whilst the sister presides at the instrument table, handing instruments and threading needles. The ward sister hands towels, swabs, and dressings, by means of a sterilized forceps, direct from the tins as required. The arrangement whereby the sister attends to the instruments and threads needles has some advantages, but from the teaching point of view it is better, I think, to let a dresser take this work, as it makes him familiar with the use of instruments and the steps of the operation.

INFECTED AND ACCIDENTAL WOUNDS

The treatment of wounds which are not aseptic involves the employment of technical methods not less important in principle or in detail than those which are demanded for aseptic operations. Such cases may conveniently be grouped as follows: (1) clean wounds which fail to heal by first intention; (2) operations upon septic cases; (3) accidental wounds.

In speaking of these cases it cannot be emphasized too strongly that the fact of a wound being already infected affords no excuse for slackness of antiseptic technique in a single particular; the presence of infection, on the contrary, demands, if possible, an even more scrupulous attention to all the details of sterilization and cleanliness, partly from the point of view of the particular case concerned, and partly for the safety of other cases which may have to be dealt with in the same place and by the same staff. Yet it appears to be a not uncommon belief that, a wound being already septic, less care is required as a few additional organisms more or less will make no difference. No more erroneous a supposition can be conceived. Other and different organisms introduced as the result of such carelessness into a wound already infected may produce disastrous results; the careless handling of a septic wound may be followed by the spread of infection to tissues previously uninvolved; erysipelas may follow the scraping of a sinus; and even specific diseases may be superadded to pyococcal infections.

(1) **Post-operative sepsis.** The possible sources of infection have already been discussed. When a wound which has been closed without drainage suppurates the organisms will, in the vast majority of cases, have been introduced during the operation. The possibility of infection being brought by the blood-stream from some focus at a distance has been already discussed. At present there are few facts to indicate whether this is at all a common occurrence. It is highly improbable that a clean wound ever becomes infected from without after complete closure, and the use of voluminous dressings is uncalled for. Indeed, dressings may often be dispensed with altogether, and with perfect safety. It is otherwise with clean wounds which are drained, or in which the skin has been so carelessly sutured that exudate escapes between the stitches. Probably such wounds can become infected from without, and the use of an adequate quantity of antiseptic dressings is called for.

No one can deny that suppuration does occasionally occur in clean operation wounds in spite of all precautions and under the best modern conditions of asepsis. It is not possible to state the percentage with any accuracy for many and obvious reasons. From such figures as become available from time to time it would probably be fair to say that the incidence of suppuration at the present time is from 2 to 4%. If any corroborative evidence is required of the diminution of percentage suppuration in recent years, it would be fair to point to the enormous increase in the number of patients passing through the surgical wards of a general hospital. Naturally there must be many factors contributing to this increase, but not the least important is the diminution of sepsis with its consequent delays. Whilst a case of radical cure of hernia would in the ordinary course occupy a bed for ten or fourteen days, the accident of suppuration would probably necessitate the patient staying in hospital for four weeks or even longer.

Wound infection, when it does unfortunately occur, is on the whole undoubtedly of a milder type than was formerly the case. The consequences of accidental infection are rarely very serious, and usually entail little more than a delay in healing and a lowering of the operator's self-esteem. Needless to say, whenever an operative infection occurs every effort should be made to trace its source by bacteriological examination of the pus and rigorous investigation into the whole circumstances of the operation. Three classes of septic operation wounds may be recognized, namely, those of a *mild* type, those of a *severe* type, and those of *specific infection*.

(*a*) Infections of the *mild type*, usually due to some pyogenic coccus of low virulence, become manifest some two or three days after the operation. The wound becomes painful, red, and swollen, and the patient suffers from a mild pyrexia. The removal of two or three stitches gives exit to a little serous or turbid fluid, followed in a day or two by some thick creamy pus; the slight constitutional disturbance quickly subsides. If non-absorbable sutures have been used a sinus may persist until these are either removed by the surgeon or are extruded spontaneously. It is a mistake, however, to think that catgut necessarily gives no trouble in this way, for some of the samples which have been hardened in bichromate are capable of persisting for many weeks, and may require removal.

There are some cases in which even such a mild infection is apt to be followed by serious results. For instance, it is usually held that the success of a radical cure of hernia is likely to be imperilled by even a mild suppuration. This belief is borne out by the following figures from the St. Thomas's Hospital Reports. During a period of 14 years, 203 cases of recurrent hernia were admitted, the primary operations having been performed at many different hospitals. No fewer than 45 of these had been the seat of suppuration. Again, even the mildest infection would almost certainly spoil the result of an operation for nerve suture; whilst in the case of the burying of a foreign body such as a Lane's plate, failure of asepsis would inevitably necessitate its subsequent removal.

Although, therefore, a breakdown in asepsis, if the infection be mild, need not have any serious constitutional effects, and although in many cases it would have no very serious local effects, yet in some instances it might completely spoil the result of an operation.

(*b*) **Severe infections.** Far different are the results of wound infection with streptococci or a virulent staphylococcus, and of almost any infection in the case of a patient of low resistance. Both local and constitutional effects of a serious order are likely to manifest themselves. Locally such an infection tends to produce a spreading cutaneous or subcutaneous inflammation, with involvement of lymph vessels and glands. In special regions it may take the form of a septic arthritis, osteomyelitis, peritonitis, or meningitis, and result, if the patient escapes with his life, in loss of a limb or in permanent invalidism. The constitutional effects are equally serious, taking the form of severe toxæmia, pyæmia, or septicæmia, and these may progress to a fatal termination in spite of all efforts to combat the infection.

The treatment of severe wound infections, whilst varying in detail in different regions, is based upon certain well-defined principles.

In the first place the wound must be dealt with by the provision of the freest possible drainage; in so doing cultures should invariably be taken in order that the bacteriology of the infection may be ascertained, so that if desirable the appropriate vaccine or anti-serum may be employed. It may be sufficient merely to reopen the original wound; it may be necessary to make other openings in addition. Problems of great difficulty may present themselves at this stage, for fresh incisions may entail opening up and infection of fresh tissue. For example, with an infection after an arthrotomy it may be impossible to say whether the joint itself is involved, or whether an extra-articular cellulitis is alone responsible for the symptoms. It may be advisable in such a case to refrain from opening the joint until signs of its involvement are unmistakable, for, as is well known, an effusion into a joint in proximity to a septic focus may be sterile. The wound after being opened up should be treated by whatever antiseptic method is applicable to the particular case; by packing with antiseptic gauze, continuous bath, continuous irrigation, antiseptic fomentations, and so on.

The use of strong antiseptic chemicals is neither desirable nor necessary. Efficient drainage is of itself sufficient, and this is helped by the use of wet dressings, irrigation, and baths. The application of strong chemicals will not take the place of such drainage; they are likely to do more damage to the tissues than to the micro-organisms, whilst at the same time sufficient may be absorbed of carbolic acid, mercury, or iodoform to cause constitutional symptoms of poisoning.

If signs of metastatic septic foci appear, the treatment becomes that of pyæmia, namely, amputation in the case of a limb or proximal ligature of the main vein or veins. Specific anti-bacterial or antitoxic treatment may be advisable, and will have been rendered possible by the bacteriological examination which should have been made directly the septic symptoms became manifest. Symptomatic treatment is also required. In this connexion the use of urotropin in infections of the cerebrospinal membranes may be mentioned. When this drug is taken by the mouth formaldehyde appears in the cerebrospinal fluid (Crowe and Cushing).

A consideration of the treatment of all infected wounds would carry us too far afield. The principles of treatment are the same as those of similar infections arising from other causes.

(*c*) **Specific infections.** In rare instances clean operation wounds have been infected with specific micro-organisms. It is believed that the virus of scarlet fever can gain access to the system by this means. When scarlet fever breaks out in a children's ward it happens occasionally that a child will develop the disease without exhibiting the usual faucial manifestation, and this has been noticed particularly in children with open wounds, more especially burns. No doubt some cases of 'surgical scarlet fever' are merely examples of septic rashes.

Cases are on record where anthrax has developed after operations in which catgut has been used, the infection in those cases having doubtless been due to catgut prepared from sheep infected with the disease.

Tetanus has been known to follow clean operations with sufficient frequency and recently enough to excite remark. This is a matter of the greatest importance in view of the comparatively recent increase in the use of catgut in general surgery. In 1909 W. G. Richardson [1] collected records of 21 cases of post-operative tetanus. In all these cases the ligature material used was catgut. In 14 the catgut was examined bacteriologically, and in 4 an organism was found resembling the bacillus tetani. In spite of these findings, Richardson thought that the case against catgut had not been proved, suggesting that the disease was not true tetanus, and that the organisms were supplied from the patient's intestine and were not introduced with the catgut. Following this paper 7 further cases were reported in the same volume of the journal. The operations were ovariotomy, varicose veins, tuberculous glands, carcinoma mammæ, hysterectomy, hydrocele, and hernia, and in every case catgut had been employed. In one only was a bacteriological examination made, and this yielded positive results. I have been unable to find any record of post-operative tetanus in a wound primarily aseptic in which catgut had not been used, and in view of the source of catgut, the difficulties attending its sterilization, and the high degree of resistance of tetanus spores, the case against that material appears particularly black.

[1] *Brit. Med. Journ.*, April, 1909.

In bygone days erysipelas frequently attacked operation wounds, and even now occasionally does so; but as its specific character is open to doubt, it need not be further considered in this connexion.

(2) **Operations upon cases already infected.** When an operation is performed upon a case in which organisms are, from the nature of the case, present, an even more stringent attention to the principles of antiseptic surgery is called for than in operating upon clean cases. Not only must other organisms be prevented from gaining access from without, and so producing a mixed infection, but the greatest care is required, both in planning and carrying out the operation, in order to avoid the infection of any unaffected tissues which may have to be traversed. An appendix abscess, for example, must frequently be opened after opening the general peritoneal cavity; here it is clear that a proper packing-off of the peritoneal cavity is essential in order to lessen the chances of a spreading peritonitis. The opening of a subphrenic abscess affords another example; here every effort has to be made to avoid infecting the pleural cavity through which the pus must be evacuated.

The most rigid antiseptic technique is to be observed in dealing with these cases, not only for the sake of the patient immediately concerned, but also for the sake of other patients who may have to be dealt with by the same operator with the same staff. It is hardly necessary to point out that in hospital practice, when a list of cases of all sorts has to be dealt with at a session, the cases are arranged in aseptic priority.

To take an extreme instance, few, if any, surgeons would dare to open a knee-joint immediately after operating upon an empyema, and the same principle holds good in other cases of minor infectivity; an operation for hæmorrhoids would follow, not precede, the radical cure of a hernia.

(3) **Accidental wounds.** It is inconceivable that any wound made with a non-sterile instrument and through unprepared skin should ever be germ-free. Yet many such wounds heal by first intention even in what may appear to be the most unpromising circumstances. The more cleanly cut an accidental wound is, and the less it is damaged with strong chemicals, the more likely is asepticity to be secured. The behaviour of accidental wounds, in fact, demonstrates even more clearly than that of operation wounds the efficiency of modern antiseptic methods, for there can be no serious doubt that, other things being equal, rough handling and drenching with strong chemicals may actually precipitate suppuration in an accidental wound which would otherwise heal by first intention. Any consideration of the details of treatment of accidental wounds in different regions would be out of place here, but the general principles applicable to all may be mentioned.

The disinfection of the skin surrounding the wound is the first step, and this is best attempted by painting with an alcoholic solution of iodine, the 2% solution in rectified spirit being preferred, but in its absence the ordinary tincture of iodine answers the purpose. Every effort should be directed to keeping the fluid from coming into contact with the wound.

The excision of wounds. The present war has brought out an entirely new principle, that of excision of wounds. Before the war it was the usual practice to treat all cases by aseptic principles as described, or at most in cases of dirty wounds to apply an antiseptic such as iodine, picric acid, or similar solution. The extensive experience of war, however, demonstrated the futility of these and emphasized the value of radical excision of the wound. This was based upon the sound principle that the wound surface was necessarily composed of devitalized tissue, which was a most favourable media for the development of bacteria since it lacked the reactive property of living cells. Experience showed that no matter how extensive the injury or what tissue was involved, if this devitalized tissue were removed by wide excision into healthy tissue, these wounds could be rendered sterile if the operation were performed within six hours of the receipt of the injury. Large vessels and nerves should be avoided, fragments of bone detached from periosteum removed, and wide excision with a sharp knife performed. The wound could then be closed without drainage, and in a considerable number of cases the wounds healed without suppuration. A few surgeons applied antiseptics directly to the excised wound before suture, and in those cases where the excision took place late or where it was impossible to close the wound, many used the same precaution, being convinced that the number of bacteria killed more than compensated for the devitalization of the surface cells. The excision, however, is the important part, while the application of antiseptics is still open to serious question. This excision is carried to open wounds of the thorax, the joints, the skull, and compound fractures, as well as to the simple injuries. This procedure should also be carried out in perforating wounds.

Where infection by the bacillus aerogenes capsulatus is found the application of peroxide of hydrogen with open dressing, no closure but free incision, is to be preferred. If the process has extended into the surrounding tissue, the excision of the entire body of the muscle or muscles involved should be performed and the wound left open. There is some hope that the prophylactic injection of a serum now being prepared, antagonistic to the gas bacillus, may end our fear of this dread complication.

In any soiled lacerated wound or punctured wound produced by a dirty object, or a wound in which fragments of the missile or clothing may be left, a prophylactic injection of antitetanic serum should be given. Tubercle may infect small wounds about the fingers, as also may syphilis, in those exposed to contact with these diseases. Both diseases have been known to attack tattoo marks. Anthrax is another specific disease which is liable to attack accidental wounds in persons exposed to the infection.

Conclusion. At the risk of tedious repetition it must be pointed out that the principles which underlie the treatment of all wounds, whether accidental or intentional, septic or aseptic, are essentially the same. The border-line between infected and non-infected wounds is not sharply defined; the transition from an aseptic operation wound to an infected one is gradual. Modern technique is directed to the exclusion of micro-organisms whether the wound is 'clean' or dirty, whilst at the same time it aims at putting the tissues in the best possible position for exercising those bactericidal powers which can so readily be depreciated by rough handling and the injudicious use of chemical antiseptics. The 'dirty' wound is handicapped at the outset as compared with the 'clean' wound, and therefore requires more and not less care in the application of the principles of aseptic treatment.

SECTION II

ANÆSTHESIA

GENERAL ANÆSTHESIA

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NITROUS OXIDE-OXYGEN ANÆSTHESIA

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LOCAL ANÆSTHESIA

BY

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SPINAL ANÆSTHESIA

BY

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CHAPTER I

GENERAL ANÆSTHESIA

SELECTION OF AN ANÆSTHETIC

IN THE selection of an anæsthetic, the question of safety during administration and of harmful effects upon the body tissues is of paramount importance. The next consideration should be the establishment of the most favorable operative condition. The patient's preference or comfort, the cost of the anæsthetic, its portability, the quickness of induction of narcosis, greater ease or convenience for the anæsthetist, the need of fewer assistants, should seldom have any weight in the decision. At present we have no anæsthetic which is devoid of all danger, and it is only through the recognition of this fact by the surgeon and the anæsthetist that the mortality from and the deleterious after-effects of anæsthesia can be minimized. Ordinarily selection is not difficult, but occasionally an intimate knowledge of the various anæsthetic substances, of their sequence and combinations, of their action on diseased and healthy organs, and of the operative requirements, becomes imperative if the best interests of the patient are to be considered.

It is first necessary to decide whether a general or local anæsthetic should be used. Of late years, general anæsthetics have been used, as a rule, in the absence of contra-indications. With increasing experience and improved methods of technique it seems probable that the field of local anæsthesia will become constantly wider. Age in itself is not a determining factor, except in so far as it renders possible the co-operation of the patient. A general anæsthetic may be given to an infant a few hours old; but certain physical conditions interdict its use, and necessitate the employment of local anæsthesia.

In the choice of an anæsthetic for children several factors come into consideration. The upper air passages of young children are sensitive to ether, especially if the vapor is concentrated; and it not infrequently causes irritation, with salivation or holding of the breath. This fact, together with the erroneous supposition that children are not susceptible to its toxic effects, has led many to the use of chloroform. Though children inhale chloroform readily, and sometimes may be rescued from conditions of respiratory and circulatory depression which might prove fatal in the adult, nevertheless many fatalities have occurred under its use. Nitrous oxide is not an appropriate anæsthetic for children under five or six years of age, as it very rapidly brings about an undesirable state of asphyxia. Children do not bear air limitation well; therefore, if nitrous oxide is used, a large percentage of oxygen must be administered with it. Local anæsthesia is usually contra-indicated in children because of the difficulty of eliminating the element of fear. As a rule ether is the anæsthetic of choice; it should always be given with a large amount of air or oxygen, as cyanosis and respiratory arrest may develop very rapidly.

Patients with valvular and other cardiac affections may be safely anæsthetized if care is taken to select the proper anæsthetic and administer it in such a manner that no undue strain is thrown upon the heart. The recumbent posture should be enforced, no deprivation of oxygen permitted, and all respiratory embarrassment and struggling during induction avoided. Asphyxial strain leads to syncope through impairment of the heart's action. The condition of the heart muscle is frequently of greater importance than the valvular lesion. In valvular lesions the intensity of a murmur depends not only upon the character and extent of the lesion, but upon the force with which the blood is driven through the diseased orifice; consequently a low murmur may mean a feeble heart muscle. In valvular heart disease the danger to life is greater from embolism than from the pure action of a suitable anæsthetic, although this danger is not so great in children as in adults. In anæmia with low hæmoglobin index the heart muscle is more or less feeble from degenerative processes, and should have the stimulating effect of ether.

In acute infections of the lung and pleura, or in recent pneumonias where an emergency operation becomes necessary and a general anæsthetic is indicated, nitrous oxide and oxygen should be employed when the age of the patient permits; otherwise, chloroform is the anæsthetic of choice. A cardinal principle in empyema is to have the patient lie on the affected side, especially if cyanosis develops when the sound side is underneath. Unfortunately this is not always possible, as many operations on the pleura or ribs cannot be performed unless the affected side is uppermost. Anæsthesia may be induced in the most favorable posture, and the position changed for the operative procedure. During the change, respiration must be carefully watched, and if cyanosis develops to any marked degree, the former position must be at once resumed. In chronic cases in which the healthy lung has become accustomed to increased work, the posture is not nearly so important as in the acute cases. When pus is in the left side with cardiac displacement, the condition is more serious than when it is situated in the right side. A particularly grave state exists when there is a communication between an abscess cavity and bronchus, since the air-way becomes obstructed with pus, gangrenous material, or blood. In such cases, it is specially desirable to keep the patient on the affected side so that the unaffected lung may remain as free as possible for respiration. Unquestionably these operations should be performed under local anæsthesia. Patients suffering with asthma or emphysema develop asphyxial symptoms under comparatively slight air limitation; they become deeply cyanosed under nitrous oxide, even when administered with a considerable percentage of oxygen. This result is also true when ether is given with a limited amount of air, but if ether is given by the open method, allowing all the air that is consistent with narcosis, no difficulty will be experienced.

Pulmonary tuberculosis does not contra-indicate nitrous oxide-oxygen anæsthesia. Ether is best avoided, especially in the acute or active forms of the disease. Ether may be administered with safety in healed pulmonary tuberculosis, providing it is not given in a concentrated form. Careful sterilization of inhalers should be rigidly enforced after their use by patients suffering from pulmonary tuberculosis.

In acute nephritis, nitrous oxide and oxygen are indicated if the age of the patient permits. In the so-called chronic nephritides ether may be safely given. In estimating the working capacity of the kidneys, the amount of albumen in the urine is of less moment than the amount of urine being excreted. Chloroform produces greater destruction of the renal parenchyma than ether. The danger to a considerable extent lies in the amount of anæsthetic which must be eliminated by the kidneys. If a good anæsthetic ether is employed and as little given as possible, combined with as much air or oxygen as is consistent with narcosis, no evil consequences may be expected. With operations not requiring profound narcosis with full muscular relaxation, nitrous oxide-oxygen is the anæsthetic of choice.

In operations about or within the mouth, jaw, nose, pharynx, or larynx, the anæsthetist should ascertain the precise nature of the operation, and the requirements of the surgeon as regards the posture desired or necessary for the operation. With our present methods of anæsthesia, it is possible to anæsthetize patients satisfactorily in any operative position. When general anæsthesia is required, short operations may be performed under nitrous oxide and oxygen. When a continuous or protracted anæsthesia is desired, an ether anæsthesia is in all respects more satisfactory. Anæsthesia is induced by inhalation with a cone, and when narcosis is well established, intrapharyngeal or intratracheal insufflation is practised. Owing to the inflammable character of ether and ethyl chloride, care must be taken if the actual or galvano-cautery is being employed. In such cases, if ether is being used and the subject has been deeply anæsthetized, the "available anæsthesia" will be, as a general rule, sufficiently long to finish the operation. The ether and cone should be removed, and thin gauze sponges saturated with warm saline solution placed around the operative field and in the mouth, to prevent the breath from catching fire and to increase the available anæsthesia by preventing to a considerable extent the elimination of the ether by the lungs.

Retropharyngeal abscess, if possible, should be opened under local anæsthesia because of the danger of the pus entering the larynx. If a general anæsthesia must be employed, ether given to a light degree of narcosis, with the patient on his side or in the Trendelenburg position, is advisable.

Cellulitis of the neck, with œdema of the tissues about the larynx and trachea which may increase during narcosis, makes any patient a hazardous risk for general anæsthesia, unless the swelling is at the side and does not cause respiratory distress. Acute inflammatory swellings may become aggravated under anæsthesia and convert a moderate respiratory obstruction into a serious one.

Laryngeal growths and tumors of the epiglottis are an obvious source of asphyxial danger during their removal, and a preliminary tracheotomy should be performed, or preparations made for doing so, if the occasion demands. A general anæsthetic is especially hazardous when the trachea is pressed upon by enlarged glands or mediastinal growths, such as an aneurism, because the asphyxia cannot be relieved by tracheotomy. When a patient is so desperately ill that the administration of oxygen is considered advisable, and operation is imperative, local anæsthesia should be employed. A fatal issue is almost sure to result if a general anæsthetic is given.

When a rigid chest wall or obstructive growth produces sufficient dyspnœa to cause cyanosis, and the accessory muscles of respiration are called into action, general anæsthesia becomes fraught with danger. These muscles are brought into use only when the ordinary muscles of respiration are inadequate, and are as readily paralyzed by the anæsthetic as are the other voluntary muscles of the body. Abdominal breathing is about half as efficient as thoracic expansion. With a rigid chest, aeration in the deeper bronchi takes place only by diffusion of gases; consequently the induction of anæsthesia is usually delayed because of the retarded absorption, and when anæsthesia is established, recovery is delayed because of retarded elimination.

Patients suffering with intestinal obstruction are usually toxic, and their reflexes are sluggish. In the early stages of the trouble ether may be safely given, but when reversed peristalsis occurs, with regurgitation of the contents of the stomach and intestines into the mouth, there is grave danger of aspiration of septic material into the larynx and lungs. When this form of vomiting exists, local anæsthesia is indicated, and can usually be successfully employed because of the blunted sensibilities and moribund condition.

In large abdominal tumors or ascities there is often considerable respiratory embarrassment, due to the limited thoracic action caused by the impeded descent of the diaphragm. Air deprivation should be avoided as much as possible in these patients. Occasionally it becomes necessary to anæsthetize them in the semi-recumbent or lateral posture, and place them in the dorsal position after the distention is relieved. As is the case with heart lesions, the induction of narcosis should be very gradually conducted, allowing more air or oxygen than ordinarily.

In spinal cord lesions, laminectomy, and cerebellar tumor operations, the prone position must be assumed, which may interfere to a considerable extent with respiration, especially in a fleshy patient. By placing a sand bag under each shoulder and under each iliac spine, lung expansion will be facilitated.

Complete muscular relaxation is not usually necessary for the reduction of recent fractures and dislocations, therefore nitrous oxide-oxygen alone, or combined with a very small amount of ether, is the anæsthetic of choice. Fractures and dislocations of long standing are more difficult to reduce, and require relaxed muscles. In this type of patients, and in open operations, deep ether narcosis is generally indicated.

Septic patients pass into narcosis very quickly and with a marked absence of excitement and rigidity. Such patients are susceptible to narcotics, and small quantities only are required to induce and maintain anæsthesia. It is very important in this class of patients that there should be no mechanical hindrance to free respiration, and that an abundance of air be allowed throughout the narcosis. Nitrous oxide is best avoided in the exhausted and collapsed subject. Ether given by the open method will help stimulate the respiration and circulation, and though this improvement does not last long, yet it is the safest anæsthesia for these subjects. The profuse sweating which is so common in septic patients is an indication of exhaustion.

The extent to which hæmorrhage will modify the phenomena of anæsthesia will depend upon the general physical condition of the patient and the amount of blood lost. The pulse will be more seriously affected by the sudden loss of blood than if the same amount were lost over a longer period of time. Anæmic patients require very small quantities of anæsthetic to induce and maintain narcosis. These subjects are very intolerant of air limitations, for the asphyxial state develops in a remarkably short time, especially if nitrous oxide is given with insufficient oxygen. Three or four inspirations of pure nitrous oxide are sometimes sufficient to produce clonic spasms or epileptiform movements—a condition which always indicates an asphyxial state. Cachectic and feeble children require remarkably small doses of any anæsthetic. Shock is precipitated by hæmorrhage and is indicated by pallor of the face and surface of the body, cold sweat, especially of the forehead, shallow breathing, and a rapid small pulse which becomes irregular in force and rhythm. When this condition supervenes, the anæsthetic must be suspended, as pain sensation is no longer present. Infants, anæmic, and cachectic subjects are naturally more seriously affected by the loss of blood than robust individuals, and consequently, if depression develops, little if any anæsthetic must be administered. The greater the quantity of blood lost, the smaller is the amount of anæsthetic which will be required. Surgeons generally hold that there is danger in the employment of general anæsthetics when the color index is below 50 per cent. Mikulicz suggested 30 per cent hæmoglobin as the lowest limit. The author has anæsthetized a patient with an index of 18 per cent, and several whose hæmoglobin was between 20 and 30 per cent, without untoward effects. The operations were made necessary through repeated or continued hæmorrhage, and were of such a nature as to demand a general anæsthesia. The danger to life is greater when the anæmia is chronic and depends upon some disease of the blood-making organs than when it is acute as the result of hæmorrhage.

The drowsy or semi-conscious patient will require very small quantities of the anæsthetic. When coma is present, no anæsthetic is indicated. Patients suffering from depressed fractures, intracranial hæmorrhage, and cerebral abscess are frequently in a more or less comatose or lethargic state, and will require little anæsthetic. Subjects of cerebral and cerebellar tumors may display symptoms of respiratory failure from increased intracranial tension, and should such a patient be anæsthetized even lightly, breathing may be completely suspended. No anæsthetic, or very little, is required for patients suffering from severe shock following accidents. When shock develops during an operation the anæsthetic should also be suspended, as in such a condition the sense of pain is abolished.

Nitrous oxide-oxygen may be used to advantage in diabetes patients, but ether anæsthesia is unattended with risk if the diabetic patient is "under control," that is, if sugar is absent from the urine, or only present to a slight extent. When the quantity of sugar is abnormally large, and the operation protracted, especially if acetone and diacetic acid are present in the urine, the vital processes may be so disturbed as to precipitate diabetic coma. Becker reports three fatalities, and found records of twelve others, following anæsthesia in diabetic subjects whose urine contained acetone at the time of operation. The presence of acetone and diacetic acid indicates a course of alkaline treatment before operation, which should be continued till the urine is alkaline. Because of the great danger of secondary chloroform poisoning, this agent is best avoided, and ether or nitrous oxide-oxygen chosen when a general anæsthetic is indicated.

Epilepsy, per se, is not an indication for or against any special anæsthetic agent. Convulsions may occur during the induction and maintenance of narcosis in both the symptomatic and idiopathic types, regardless of the anæsthetic used or the method of its administration. The pre-operative preparation of epileptic patients is important, as they are nearly always constipated, and in more or less of an acidosed condition.

Fleming, in a review of inquests held in England, showed that out of 700 deaths occurring during anæsthesia, 521 were due to the anæsthetic. Of these patients, 223 died before the operation was begun. His statistics are interesting and instructive.

Chloroform	378
Ether	28
C. E., A. C. E., and A. C.	100
Nitrous Oxide	12
Ethyl Chloride	6
Spinal	8
Scopolamine	2
Local	6
Not specified	160

In analyzing these figures, one is at once impressed with the dominance of fatalities under chloroform and it is difficult not to attribute them to the improper selection of the anæsthetic agent, although the inexperience of the administrators may have been a contributing factor. Fleming is undoubtedly correct in his belief that this appalling death rate would not have occurred if ether had been administered instead of chloroform. From a purely scientific point of view, these statistics serve to show the great need of reform in the selection and administration of anæsthetics.

CHLOROFORM

The precise action of chloroform upon the mammalian organism has occupied the attention of investigators in medicine, surgery, and pathology in every land, ever since the discovery of its anæsthetic properties. The result of these investigations has shown that, in addition to its anæsthetic action, chloroform has a powerful depressant action upon the heart. In consequence of the dilatation and diminished power of the heart under its influence, the blood is driven with less force into the arteries; and as the pressure falls, the blood supply to the medulla decreases, with a consequent diminished functional activity of the centers of respiration and circulation. When the dilatation is sudden and extreme, the heart fails, although rhythmic movements may persist for a time. Although there are some who still regard chloroform as a drug which acts primarily upon the vasomotor center, the present evidence indicates that the fall of arterial tension which occurs is due to the direct effect of the anæsthetic upon the heart itself; and that while respiration usually ceases before the heart fails, it is the effect of the anæsthetic upon the circulation, and not its influence upon the respiration, which is the essential factor in the cause of death.

It is well known that the administration of chloroform may be followed by well marked pathological changes in the tissues, the most conspicuous of which are œdema, fat infiltration, multiple hæmorrhages, and necrosis of the central portion of the liver lobules. At present there is no adequate explanation of how these changes are produced. The process appears to be identical with those concerned in poisonings with a large group of toxic substances, including other narcotics, arsenic, salvarsan, phosphorus, and possibly bacterial poisons. There is considerable evidence to show that in chloroform poisoning the liver necrosis is produced chiefly by the action of hydrochloric acid, which is formed in the metabolic destruction of chloroform. Ether does not produce necrosis. It only produces œdema and fat infiltration to a less degree.

In 1866, Nothnagel ([2]) showed that the introduction of chloroform into the stomach or subcutaneous tissue of rabbits was followed by fatty degeneration of the liver, kidney, and heart muscles. Casper ([3]), in 1850, expressed the belief that chloroform might produce a chronic poisoning which might cause death after anæsthesia. In 1894 Guthrie ([4]) reported a number of cases at a children's hospital in which chloroform narcosis was followed in from 12 to 24 hours by severe toxic symptoms, copious, violent, and persistent vomiting, restlessness, loud screaming, delirium, pyrexia toward the close of the case, and coma. The breath had a sweetish odor, and the urine contained acetone and diacetic acid. Death usually occurred about the fifth day. Becker ([1]) found that acetonuria was especially liable to follow the anæsthesia of children.

The most noteworthy feature in cases which have come to autopsy has been the fatty changes in the liver, heart, and kidneys. In some of the reported cases the liver changes have been described as yellow atrophy, fatty degeneration, or fatty infiltration. Scott-Carmichael and Beattie ([5]) reported a fatal case in which autopsy showed the liver distinctly enlarged, intensely fatty, and almost creamy yellow in color. When stained for fat, it was seen that all the cells from the center to the periphery of the lobule were crowded with fat globules. The kidneys and suprarenal bodies also showed fatty degeneration. Bevan and Favill ([6]) reported a fatal case in a twelve year old child, whose urine was negative before operation, but which showed on the third day after operation an acidity of 11.6, diacetic acid, acetone, albumen, hyaline, granular and waxy casts. The breath had a sweet acetone odor. At autopsy the liver was found enlarged, firm, universally yellow, with no lobular centers. Microscopically the liver showed advanced fatty changes at the peripheries of the lobules, the central portions were congested, and the columnar arrangement of the liver cells thrown into disorder. The kidneys showed fibrous changes, the most striking change being the presence of large amounts of granular material (coagulated serum) in the cavities of the glomeruli, visibly compressing many of the tufts. The convoluted tubules were filled with a similar granular material, while the epithelial cells were well preserved. The authors were able to find 27 other fatal cases reported in the literature.

Beesly ([7]) considers the symptoms occurring in so-called acid intoxication, acidosis, acetonuria, and delayed chloroform poisoning as pointing to a metabolic disturbance in the organism, one of the ultimate products of which is acetone. He examined, before and after anæsthesia, the urine of a large number of children at the Royal Hospital for Sick Children, and found that both ether and chloroform produced a temporary acute acetonuria, but that if acetonuria were present before operation, chloroform proved to be far more dangerous than ether. Thus of 19 cases operated upon under chloroform, no less than 14 died, all exhibiting symptoms of acid intoxication or acetone poisoning. Autopsies showed the usual fatty degeneration. Of 24 patients operated upon under ether, only two died, neither of them as a result of acid intoxication.

Graham ([8]) found that "when pregnant animals were chloroformed, their offspring showed changes characteristic of the pathological and clinical pictures of the various hæmorrhagic diseases of the new-born," suggesting that there might be a causal relationship between chloroform used at labor, and the occurrence of some of these various conditions in the new-born. In a further series of experiments he found that, even in doses sufficiently small to produce anæsthesia for ten or fifteen minutes in the pregnant animals, intra-uterine death and abortion frequently occurred, with definite fatty changes in the liver of the offspring. By administering alkali simultaneously with the chloroform, he found that liver necrosis was prevented or greatly inhibited, and he concluded that the acid intoxication resulting from tissue asphyxia was the essential element in the fatal outcome.

Chloroform for anæsthesia should be transparent, colorless, and neutral to litmus paper. It should possess an agreeable, non-irritating odor, and upon evaporation should leave no residue or strong odor. It should form no precipitate when added to a solution of silver nitrate. It is decomposed by light and air, and therefore should be kept in colored, well-stoppered bottles. Chloroform boils between 140.2° and 141.8° F. Its density is four times that of atmospheric air. If it is being administered for some time in a closed or badly ventilated room, in the presence of an open flame, gaslight, or an oil or gas stove, the vapor is decomposed, with the production of exceedingly irritating fumes, composed principally of hydrochloric acid and chlorine. The occupants of the room may be affected with smarting of the eyes, a spasmodic cough, and a feeling of tightness about the chest. The fumes may be neutralized to a certain extent by hanging in the room towels wet in ammonia water. Chloroform is very caustic in its action on the skin; consequently care should be taken to protect the face during the administration by anointing it well with cold cream or vaseline. Corneal ulcers have been known to develop from the dropping of chloroform into the eyes. When this accident occurs, an immediate instillation of olive or castor oil will prevent unfortunate complications. The necessity of keeping the lids closed and the eyes well protected with moist cotton during the administration of chloroform is obvious.

Of the various methods of giving chloroform, that in which it is dropped upon a mask covered with gauze gives the best results. Six or eight layers of gauze are preferable to stockinet for the cone cover. If stockinet is used, the cone should not rest on the patient's face, as there is danger of a too concentrated vapor being administered. A small drop can be secured by drawing the end of a cotton wick out to a fine thread. If a small drop and fairly thin cone cover are employed, a vapor varying from one to four per cent will result, depending upon the rapidity of the dropping. The ideal to be sought for is to give a well-diluted vapor continuously.

In giving chloroform to a child, great care must be exercised if he cries during induction. Because of deep inhalation, an overwhelming dose may be easily administered. It is dangerous to "push" chloroform in order to secure surgical narcosis or relaxation more quickly. The general laws which apply to ether narcosis prevail in chloroform anæsthesia. The respiration, circulation, and pupillary reaction must be constantly watched.

ETHER

Ether is a transparent, highly volatile liquid, possessing a characteristic pungent odor and burning taste. It boils at a temperature of 96° F. under ordinary atmospheric pressure. It is miscible with alcohol and chloroform, and soluble in water to the extent of ten per cent. Pure ethylic ether should be neutral to litmus paper, and should evaporate without leaving a distinct or foul-smelling residue. It should form a clear mixture in any proportion with oil of copaiba. It is decomposed by light and air, and therefore should be kept in well-stoppered cans or dark bottles. It is highly inflammable, burning with a white luminous flame. Any ether which forms snow on the cork or wick when left standing, or which freezes on the cone cover during administration, should be discarded as being unsuitable for the open method of anæsthesia. With such an ether, it is difficult, often impossible, to maintain an even, smooth anæsthesia.

Ether is more potent than nitrous oxide and less potent than chloroform. By reason of its low boiling point (96° F.) it is quickly eliminated, chiefly by the lungs, and in small part by the kidneys and gastro-intestinal tract. It escapes from the body unchanged.

Ether causes a rise of arterial pressure by stimulating the vasomotor center and the heart. In moderate amounts it increases the force and frequency of the pulse by its effect upon the heart muscle. Large doses, however, act as a cardiac depressant, especially if there is an accumulation of carbon dioxide in the circulating blood. Poisonous doses produce death by paralysis of the respiratory center. Unlike chloroform, it is one of the most energetic stimulants known to the respiratory and circulatory systems. Ringer ([9]) found that one or two minims of chloroform arrested the ventricles of the frog's heart, but that fifty minims of ether simply accelerated and slightly weakened the beats.

Temperature of the ether vapor. That there is any advantage in warming ether vapor to body temperature has been questioned by such able observers as Seelig ([10]), Meltzer ([11]), Cotton and Boothby ([12]), Bevan ([13]), McCarthy and Davis ([14]), and others. Seelig states that ether vapor radiates its acquired heat so rapidly that at a distance of one meter from the source of heat it practically assumes room temperature. McCarthy and Davis do not believe that warm ether vapor is less irritating to mucous membranes than unheated vapor, or that it conserves the energy of the patient by lessening the elimination of heat from the lungs. They have found that the maintenance of surgical anæsthesia required the same degree of concentration, approximately six per cent, of the warmed or unwarmed vapor. This agrees with Connell's findings. In vaporizing ether, there is an advantage in warming the liquid ether, not because of any value in warm vapor, but because when air is forced over or through liquid ether, the warm ether vaporizes more rapidly, and consequently less air is required to carry the same amount of ether.

Nature has carefully protected the lung alveoli by placing between them and the external air a long passage through which air must pass before reaching them. During the transit the air is warmed to body temperature. Were this not true it is doubtful if warm-blooded animals could exist in the polar regions. Of much greater importance than warming the ether vapor is the conservation of the body heat during anæsthesia. Vierdordt gives eleven calories per hour as the normal elimination of heat by the lungs, and ninety calories by the skin. When these figures are contrasted, the necessity of preventing the loss of heat by the skin through radiation, evaporation, or conduction is apparent. Boothby says, "From a calculation of the loss of heat directly attributable to warming anæsthetic vapors, it is demonstrated that such a loss is negligible in comparison to that from the body surface."

ETHYL CHLORIDE; ETHYL BROMIDE

Ethyl chloride is a colorless liquid, with an odor somewhat like that of chloroform. It boils at a temperature of 12.5° C. It is highly volatile, and consequently is kept in sealed glass tubes. The effects produced by ethyl chloride come about very quickly, so that consciousness is lost in a few seconds. In the rapidity with which it abolishes consciousness it resembles nitrous oxide; on the other hand it is like chloroform in the suddenness with which it destroys life when administered in an overdose. Children and alcoholics are especially susceptible to its influence.

It may be administered by spraying it inside of the cone or on the gauze of the vaporizing chamber of the inhaler. Better results, however, appear to be obtained by the closed system, in which the ethyl chloride is placed in a bag, into which the patient breathes. The quantity required to produce anæsthesia will depend upon the age, characteristics, and general physique of the subject, the method by which the drug is given, and the extent to which air is permitted to dilute the vapor. Like nitrous oxide, a comparatively small quantity will produce a powerful effect if the air is restricted and rebreathing be freely employed. If the inhaler with a bag is used, 1 – 2 ccm. will usually be sufficient to produce anæsthesia in children, and 2 – 3 ccm. will anæsthetize most adults; 4 – 5 ccm. may be required for very strong men. When it is administered by the closed method, anæsthesia is produced in a few seconds. It is important to remember that anæsthesia may deepen after the removal of the inhaling apparatus, because of the continued absorption of the vapor from the lower air passages. This is particularly true in children, especially if there is any obstruction to breathing, such as is commonly present in patients with hypertrophied tonsils and adenoids. Narcosis is so rapidly induced that is is difficult or impossible to recognize any stage or degree in the administration. After a few breaths there may be a moment of exhilaration; then consciousness is suddenly lost. Occasionally a short period of struggling occurs. If stertorous respiration develops the administration should be stopped or more air allowed.

The color of the patient does not change during full narcosis; consequently it can be readily seen that the limit of safety may be overstepped, and the patient plunged into a dangerously deep degree of narcosis without any warning symptom. Its administration is especially dangerous as a preliminary to chloroform anæsthesia, because both drugs markedly depress the circulation. When it is used as a preliminary to ether anæsthesia, it is advisable to add the ether slowly while still administering the ethyl chloride, as is practised in the nitrous oxide-oxygen-ether sequence.

The use of ethyl chloride has been practically restricted to short operations or incomplete narcosis, or to inducing anæsthesia before giving ether. The margin of safety between the stage of surgical anæsthesia (muscular relaxation) and a lethal dose is too small for its employment as a general anæsthetic agent. By dentists it has been quite extensively employed for extraction, opening abscesses, preparing sensitive cavities, and removing pulps. Headaches, nausea, and vomiting are more apt to follow the administration of ethyl chloride than of nitrous oxide. Its only advantage over nitrous oxide is that it is more easily portable and requires no special apparatus for its administration. On the other hand, nitrous oxide-oxygen may be administered continuously for hours without any untoward effects. There has been a considerable diminution, recently, rather than an extension, in the use of ethyl chloride, due to the numerous accidents that have occurred under its influence. There is good reason to believe that the risk attending its administration is considerably greater than was at first supposed. Authorities are now quite generally of the opinion that ethyl chloride is as dangerous as chloroform. Statistics would seem to prove that its mortality rate is from 1 in 2,000 to 1 in 3,000. Lee's report, based on 5,575 administrations in the Pennsylvania Hospital, shows five deaths, a mortality of about 1 in 1,000. Though small doses may increase the force of respiration and raise blood pressure, large doses depress both functions, producing an irregular pulse and rapid respiration. Death is due to respiratory failure which precedes cardiac failure.

Ethyl bromide is a transparent, colorless, volatile liquid, of a sweetish odor and pungent taste. When it is administered with a closed inhaler, anæsthesia is produced in about sixty seconds, and recovery is correspondingly speedy. From 4 to 6 ccm. are placed in the inhaler and little or no air is admitted for the first few inhalations, after which the air cap of the apparatus may be opened. Ethyl bromide is decomposed by air and light, and therefore should be kept in hermetically sealed dark-colored bottles. It has the same physiological effects as ethyl chloride. It does not produce muscular relaxation unless the anæsthesia is very profound. The accidents which have been reported under its use have been sudden, early cardiac failure and respiratory paralysis. It has never been employed to a very great extent, but sufficient statistics have been collected to indicate that it is more dangerous than chloroform. As compared with nitrous oxide it is distinctly inferior, not only in point of safety, but in the greater liability to unpleasant after-effects, such as headaches and nausea.

ANÆSTHETIC MIXTURES

A large number of mixtures of various anæsthetics have been recommended from time to time. They are much more popular in England and continental Europe than they are in this country. The most common are the so-called A. C. E. mixture, composed of one part of alcohol, two of chloroform, and three of ether; the Billroth mixture, composed of one part of alcohol, three of chloroform, and one of ether; and the Vienna mixture, consisting of one part of chloroform and three of ether.

It was supposed that the alcohol antagonized any depression produced by the anæsthetic, increased the stupefying effects of the ether and chloroform, and also prevented a too concentrated chloroform vapor from being respired, thereby counteracting any tendency to circulatory depression. A better knowledge of the physiological action of alcohol has proved the idea to be fallacious. The number of accidents under the use of these mixtures is very considerable, and they are by no means as safe as ether alone, although perhaps less dangerous than chloroform alone.

The objection to such mixtures is that the constituents have not the same rate of vaporization. The more volatile agent will vaporize first leaving the less volatile to be respired subsequently. Further, the more volatile the anæsthetic, the less there will be absorbed by the blood in a given time, and the more rapid will be its elimination. Chloroform has a high boiling point and consequently is rapidly absorbed and slowly eliminated, owing to the temperature of the blood being below its evaporation point, while the contrary is true of ether. The A. C. E. mixture has given results very similar to those of chloroform, especially when the supply of air has been limited.

THE USE OF SEDATIVES BEFORE ANÆSTHESIA

There is a wide disagreement among competent anæsthetists and surgeons upon the wisdom of giving alkaloidal sedatives before anæsthesia. In some clinics the use of morphine with atropine before the administration of an anæsthetic is a routine procedure; in other clinics atropine alone is used; and in still others no preliminary medication whatever.

Atropine, as is well known, checks all the glandular secretory activities. It is used for its inhibitory effects on the secretion of mucus in the upper respiratory tract, both to prevent the accumulation of mucus which may act as an obstruction to free respiration, and to lessen the likelihood of its aspiration into the trachea and bronchi. Sometimes its administration is of distinct advantage, but in a majority of cases turning the patient's head to one side will permit the excessive secretion to escape from the mouth, and obviate the danger of its aspiration into the air passages.

The advantages urged in favor of morphine are that it allays the apprehension of the nervous patient, and renders the psychic element of less importance; that it makes the induction of anæsthesia easier; and that it renders possible the maintenance of complete anæsthesia with a smaller quantity of anæsthetic. Those opposed to the use of morphine argue that these advantages are of slight importance compared to the disadvantages incurred; that by the use of tactful suggestion the patient's fears may be readily allayed; that by giving the anæsthetic slowly, anæsthesia may usually be induced without resistance on the part of the patient; and that the use of a slightly increased quantity of anæsthetic is far less important than the administration of a concentrated anæsthetic for a brief time. The disadvantages of giving morphine are: (1) that it depresses respiration, thereby rendering anæsthesia more hazardous, and prolonging the period of recovery because of retarded elimination of the anæsthetic; (2) that it abolishes the pupillary reflex, an important guide to the degree of narcosis; (3) that it frequently causes post-operative nausea and vomiting. Because of these disadvantages the author prefers to dispense altogether with the use of sedatives before anæsthesia.

PREPARATION OF THE PATIENT FOR GENERAL ANÆSTHESIA

To secure an ideal anæsthetization, it is essential that attention be paid to details before and during the administration of anæsthetics. This is important in the so-called minor as well as in major operations. It is a generally accepted fact that the best time for the administration of an anæsthetic is in the morning. Patients are not only fresher and brighter after the night's rest, but the stomach is empty and in a state of quiescence.

When operation is not urgent a twenty-four hour specimen of urine should be secured in order to determine if the normal amount of urine is being secreted, for renal complications seem to appear more frequently in patients with scanty urine. When a lessened secretion is not due to a nephritis, the free administration of pure or an alkaline water in order to flush the kidneys will be of advantage. The urine should be examined microscopically for blood, granular, waxy, or hyaline casts; and chemically for albumen, sugar, acetone, and diacetic acid. Before the patient is taken to the operating room, a careful physical examination should be made of the chest as a matter of routine. The circulatory system in patients past middle life should receive special attention. When operation is not urgent, rest and treatment to improve the heart condition may be indicated before operative measures are undertaken. If the blood pressure is abnormally high, it should be brought to approximately normal limits by rest and proper dietic treatment.

On the day preceding the operation, there should be as little deviation as possible from the usual routine. Purging and too strict limitation of the diet before operation are not to be recommended, as they exhaust the patient and disturb metabolism. Unless the bowels have been moving freely it is usually advisable to administer a mild laxative the preceding night, or an enema several hours before the time set for operation. The salines are best avoided because watery stools dehydrate the patient. Patients in good health may be allowed their usual meals; but it has been observed that if carbohydrates are given, with a restriction of other foods, there is less likely to be vomiting or the development of acidosis. Glucose is valuable as a food and helps to combat acid intoxication. It may be given with water and lemon juice for several days before operation, and by rectum or intravenously (2.4 per cent) following operation, especially in cases of delayed chloroform poisoning. In cases of toxæmia, especially in victims of a subacute or chronic affection, more sugar than can be given by mouth should be administered. In such cases rectal administration of 6 per cent anhydrous dextrose by the drip method often gives good results. If the urine contains acetone and diacetic acid, an alkaline treatment should be instituted for at least twenty-four hours before operation. The production of incompletely oxidized acids is not influenced by alkali, but by saturating the patient till the urine is distinctly alkaline the retained acetone bodies will be eliminated. The quantity of alkali which is required to make the urine alkaline is an indication of the amount of acetone present in the body. Bicarbonate of soda may be given in from five to ten grain doses with water every two or three hours. Fruit juices are oxidized into carbonates and consequently represent an alkali administration.

As a general rule, no solid food should be taken for at least six hours before the administration of a general anæsthetic, since an empty stomach is one of the most efficient preventatives of vomiting during or after the administration of an anæsthetic. The author has never seen any difficulty attributable to a six or eight hour fast, but has frequently met with difficulties of a respiratory character due to the presence of undigested food in the stomach. A smooth, even anæsthesia is almost impossible with a distended stomach, as respiration is more or less hampered, relaxation of the abdominal muscles is delayed, and unless the patient is profoundly anæsthetized there will be retching or vomiting, with the added danger of aspirating pieces of undigested food into the bronchi, with a resulting pneumonia, lung abscess, or immediate death through strangulation. Debilitated patients may be allowed small quantities of easily digested food, as gruels of barley or rice, up to within three or four hours of the operation. These carbohydrates have the advantage over animal broths in that they materially assist in the storing of glycogen in the liver. Infants should be nursed to within two or three hours of the operation.

The bladder should always be emptied before narcosis is induced. Whether the patient should void or be catheterized will depend upon the judgment of the operator. Many surgeons feel that there is an added danger of a possible bladder infection from catheterization.

Before a general anæsthetic the patient should be directed to rinse the mouth and throat carefully with some antiseptic solution, such as peroxide, one part to three of water, or a weak solution of alcohol. This precaution is especially important in individuals who have bad teeth and those who have tonsillar infections. The mouth should be examined for artificial or loose teeth or foreign bodies, such as tobacco, chewing gum, etc. The danger of aspirating these bodies into the larynx or lungs with serious consequences is obvious. The clothing about the neck and chest should be loosened in order that it may not impair respiration or interfere with the circulation in the great vessels of the neck.

In operations upon the stomach this organ should be carefully washed out by means of the stomach tube and pure water or saline solution. The operation is thus made much easier and the danger of infection through leakage is greatly lessened. In emergency operations the stomach may be emptied through the stomach tube if solid food has been eaten within five or six hours.

DIFFERENT METHODS OF PRODUCING ANÆSTHESIA

The different methods for the induction and maintenance of ether anæsthesia are the inhalation, venous or arterial, and rectal. The most convenient and reliable channel for the introduction of anæsthetic agents into the organism is undoubtedly through the respiratory passages. In inhalation anæsthesia, as the term indicates, the anæsthetic is breathed, and enters the system through the lungs. It may be delivered to the patient by the open, valvular, closed or rebreathing, intrapharyngeal and intratracheal methods.

Open Ether. In the open method, a copious quantity of atmospheric air gains access to the lungs throughout the anæsthesia and all expirations escape into the surrounding air. At the same time the method permits the anæsthetist to administer adequate quantities of ether vapor. The term "semi-open" is applied when a limited amount of air is admitted.

A 4 or 8 ounce can of ether, the size depending on the estimated time required for the operation, is fitted with a cork, into the opposite sides of which two grooves of unequal size are cut. In the larger of the two

FIG. 1. ANÆSTHETIC SCREEN.

grooves is placed a wick of cotton which reaches nearly to the bottom of the can and extends about an inch beyond the cork. If the cork and wick are properly arranged, a full, steady drop will be secured. The rate of drop can be controlled by the angle at which the can is tipped.

Before the administration is begun, the patient is told to breathe naturally and not to force respiration. While the mask is held away from the face the ether is slowly dropped on various points of the cover. As the patient becomes accustomed to the odor the mask is gradually lowered till it rests on the face. The rate of dropping is now increased until the entire cone cover is moist. In a few minutes a piece of gauze is placed around the cone, or the cone may rest on a gauze ring pad which encircles the nose and mouth, to shut out the air which passes under it; thus all the air which the patient receives is more or less impregnated with ether vapor. When the cone cover is too thick, as, for example, when two layers of stockinet and ten or twenty layers of gauze are used, the method ceases to be open and may be termed the semi-closed method. With the latter technique more ether is required to moisten the cover, and the patient's exhalations to a considerable degree are retained within the cone, and are reinhaled. The oxygen supply is thereby greatly diminished, the effect of which is shown by more or less cyanosis. Two layers of fine, closely-woven stockinet, or its equivalent in gauze, should cover the mask. If the cover is too thin, it is difficult or impossible to induce and maintain anæsthesia. The ether should be dropped continually on the cone. If the dropping is suspended till signs of returning consciousness appear, an uneven narcosis results. Intermittent administration has the further disadvantage or danger of administering a too concentrated vapor in the attempt to get the patient under again. It should be remembered that a concentrated vapor will do more injury to lung epithelium in a few minutes than a dilute vapor will do during a long anæsthesia. It has been shown that a 6 or 7 per cent vapor is the greatest concentration which can be inhaled without irritation to the mucous membrane of the air passages and the alveolar epithelium.

The depth of narcosis is controlled by the amount of ether dropped on the cone and can be varied to suit the operation. To have the cone more than saturated is a waste of ether, as it will run off the cover. When the proper technique of the open method of etherization is carried out, narcosis develops along the lines of natural sleep, and it is a rare exception not to have a smooth anæsthesia with relaxed muscles and perfect oxygenation throughout the most difficult operation. Contrary to the teachings of some anæsthetists, we have no hesitancy in saying that, barring operations which call for insufflation (intrapharyngeal, intratracheal) anæsthesia, the open method is suitable for any patient or any operation in which ether is the anæsthetic of choice. The author has employed it with equally good results at ages ranging from thirty-six hours (spina bifida) to ninety-six years (carcinoma of the face); and in all conditions of health from the marasmic infant to the athlete, from the frail patient suffering with severe heart lesions to the obese alcoholic. Observation has clearly demonstrated that trouble during induction and maintenance is invariably due to faulty technique and not to the open method of etherization.

One of the greatest advantages, if not the greatest, which this method possesses is the large amount of oxygen which the patient constantly receives. This fact is readily determined by observing the ears, face, and color of the blood. Blood oxygenation is normal throughout the narcosis, so that the toxic effects of the anæsthetic are reduced to a minimum.

The difference in anæsthesia as maintained by the open and closed methods is quite apparent. When an asphyxial factor is introduced, the accessory muscles of respiration assist in the effort to obtain a sufficient supply of oxygen. The result is labored breathing with more or less heaving abdominal movements. The presence of anoxæmia is evidenced by the congestion of the venous system, shown by the bluish color of the ears, lips, cheeks, and blood. The respiratory tract is especially affected by the general venous engorgement, which increases the size of the tongue and surrounding structures, and thus produces a mechanical obstruction which is further aggravated by the increased flow of mucus. Closed ether administration is particularly unsuitable for florid, stout persons, who become alarmingly cyanosed when subjected to air limitation. When, on the other hand, an abundance of air or oxygen is allowed, there is no congestion of the capillary vessels, and consequently there is little oozing of venous blood from the wound. The pulse is of good volume and blood pressure is well maintained.

Closed or rebreathing method. The apparatus used in the closed or rebreathing method as a rule contains no valves, but is arranged with stop cocks, which are under the control of the administrator. Attached to the facepiece is a bag, into and out of which the patient breathes, the air supply being intentionally restricted, and the expiratory products retained for rebreathing. There is a progressive change in the composition of the imprisoned air in the bag corresponding to the duration of the to-and-fro breathing. The admission of fresh air or oxygen must be regulated according to the susceptibility of the patient to the anæsthetic. Rapid and labored respiration, especially a strained form of expiration, cyanosis, and stertor are indications for more oxygen. It should not be forgotten that the anoxæmic factor is almost as powerful as the ether factor in this method of anæsthesia, and therein lies the chief objection to the method. The patient should be slowly anæsthetized by ether and a large amount of atmospheric air, and not by ether and his exhaled carbon dioxide.

Gatch's studies led him to the conclusion that "the severity of the pulmonary lesions found after experimental etherization by the closed method could be satisfactorily accounted for by the great concentration of the ether vapor and the greater liability to aspirate mouth contents when they are used." Dresser found that "the ether vapor within the closed mask sometimes reached a concentration as high as thirty-four per cent, while six or seven per cent is the strongest concentration which can be inhaled without irritation to the air passages." He regards any concentration of vapor, which cannot be inhaled by a conscious patient without coughing, as harmful to the lung epithelium. Poppert likewise concluded from his experiments that the greater the ether concentration, the more irritating to the lungs. Offergeld ([17]) studied the pathological changes in the lungs which occurred after an etherization lasting from seventy to eighty minutes. His results were obtained in guinea-pigs, rabbits, and cats, after using the closed method, a mixture of ether and oxygen, and the open method. The animals which did not die were killed at various periods after the narcosis. With a closed administration some of the animals died within a few days from bronchopneumonia. In others who were killed in two or three days the lungs showed patches of bronchopneumonia, fatty degeneration desquamation of bronchial epithelium and hæmorrhage into the alveoli. None of the animals that were given ether and oxygen died. If killed at the end of the first day, patches of consolidation, with some blood and desquamation of epithelium in the bronchi, were present. With the open method there were no deaths, and necropsy two days after the anæsthesia showed a perfectly normal condition of the lungs. When the closed method was used, it required four days for the mildest cases to repair.

In the valvular method of anæsthesia, inspiratory and expiratory valves are present in the inhaling apparatus. When ether or chloroform is administered, the drug is vaporized by passing atmospheric air or oxygen over or through it. In this method, each inspiration contains a quantity of the vapor, and each expiration escapes into the atmosphere. As a rule, the percentage of the anæsthetic vapor may be estimated. This is especially true when a gas, as nitrous oxide, is being administered.

There are various ingenious instruments by means of which definite percentage mixtures of ether or chloroform vapors and air or oxygen can be given. Karl Connell ([18]) has devised an apparatus, the "anæsthetometer," which undoubtedly comes the nearest to being ideal of any apparatus now in use for estimating the amount of air passing and the percentage of ether vaporized. It must be remembered, however, that the needs of the patient vary during different stages of the operation, and no device, however perfect, can supplant the watchful care of the trained anæsthetist.

Intrapharyngeal anæsthesia. Narcosis is established in the usual manner by inhalation with the cone. A fairly firm rubber catheter, the size of which will vary with the age of the patient, is passed well into the posterior pharynx. If it is too long, there is danger of its passing into the œsophagus and forcing the vapor into the stomach; on the other hand, if it does not extend through the nose, it is difficult or impossible to keep the patient asleep. If the distance between the alæ of the nose and the auditory meatus is measured on the catheter, and this length passed into the nose, it will be in the proper position. The author has observed in passing the catheter, that it meets with a slight resistance

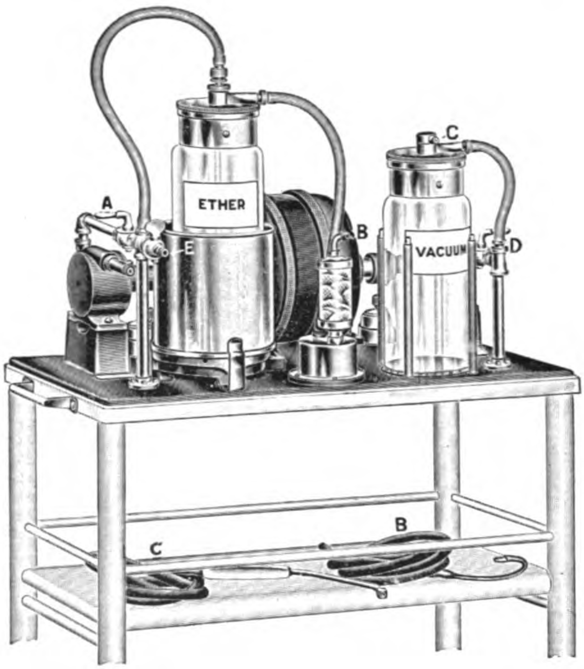

FIG. 2a. MOTOR-DRIVEN PUMP FOR USE IN INTRAPHARYNGEAL ANÆSTHESIA.

at a certain point in its passage, which is the posterior pharyngeal wall. If it is introduced about 2 inches further, it will be in proper position. The catheter should be moistened with sterile water, or lubricated with some sterile oil before the introduction, otherwise there is danger of injuring the nasal mucosa. When the catheter is properly adjusted, it may be held in position by a strip of adhesive plaster across the forehead. A single catheter may be used, or one for each side of the nose, attached to the vapor tube by a Y-connection. The vapor may also be passed through a tongue depressor or mouth gag made for the purpose. The author has devised metal tubes of various lengths, bent at the proper angle to direct the vapor into the posterior pharynx when placed in the angle of the mouth. These tubes have many advantages over the nasal catheter in nose, harelip, and cleft palate operations. The tube or catheter should not be introduced till the pharyngeal reflexes are abolished; otherwise the vapor will cause spasm or coughing. Should either of these occur the catheter should be left in position, but the vapor stopped and more ether given by the drop method.

Intrapharyngeal anæsthesia is indicated in any operation about the head, the nature of which prevents the use of a cone, such as operations upon the jaw, tongue, lip, palate, tonsils, or nose. It may be used to

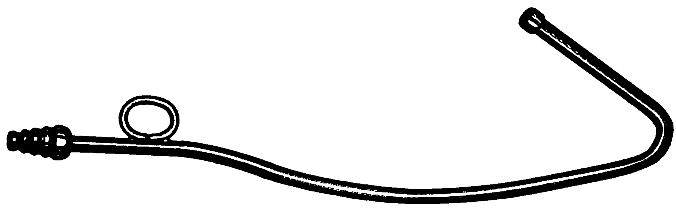

Fig. 2b. Tube for Use in Intrapharyngeal Anæsthesia.

advantage in cerebellar tumor operations or in other operations necessitating the prone position.

Intratracheal anæsthesia. In intratracheal insufflation, the ether vapor is delivered through a tube directly into the trachea a short distance from the bifurcation. The use of a catheter about half the size of the glottis permits the expired air to escape around it, and thus respiration is accomplished. A more dilute vapor is administered than is given in the intrapharyngeal method, because a sufficient volume of air or oxygen under proper pressure (15 – 20 mm. of mercury) must be allowed for the respiratory needs of the patient. This provision is especially necessary to prevent the lungs from collapsing when the intrathoracic pressure is diminished during thoracic operations. The pressure is released at regular intervals, in order to allow the lungs to contract as in normal respiration.

Anæsthesia is induced by the ordinary drop method till the pharyngeal reflexes are abolished. With the patient lying on his back, the head is extended so that the chin is on a line with the sternum. The Jackson laryngoscope, fitted with a small dry battery in the handle, is passed over the upper surface and base of the tongue until the epiglottis is brought into view. A fairly firm catheter about half the diameter of the glottis, marked 26 cm. from the tip, and with a side opening near the end, is passed through the laryngoscope into the glottis up to the mark, which should be even with the incisor teeth. In the normal patient the catheter will reach to within about 5 cm. of the tracheal bifurcation.

The distance between the glottis and bifurcation is generally about equal to the distance between the incisor teeth and the glottis.

As the catheter passes into the trachea, there is a hissing sound. If the anæsthesia is light, a more or less violent attack of coughing ensues, but regular breathing is resumed when the ether vapor is forced into the lungs. If the hissing sound is not heard, probably the catheter is in the œsophagus instead of the trachea. When the catheter is properly placed, the laryngoscope is removed, a mouth prop is inserted, and the catheter attached to the tube leading to the vaporizer. From this point, the technique does not differ from that in the intrapharyngeal method, except that the pressure must be constantly observed, and the flow interrupted three or four times a minute by pinching the tube.

Intratracheal insufflation provides for a sufficient aeration of the lungs, regardless of the respiratory movements of the patient, and when properly administered and safeguarded, it can be rendered devoid of intrinsic danger. It is indicated in all intrathoracic work, or whenever the operation may interfere in any way with voluntary respiration. Ether, with air or oxygen, is generally the anæsthetic used; nitrous oxide-oxygen may be combined with the ether if desired.

Cotton and Boothby ([10]) call attention to the danger of emphysema and of interference of circulation by excessive intrapulmonary pressure. These authors claim that a pressure in excess of 10 mm. of mercury is unjustifiably dangerous. They suggest a safety valve by means of which the intrathoracic pressure is not permitted to exceed 15 mm. mercury. Other dangers are those of spraying liquid ether into the lungs, and of introducing the tube into the œophagus or beyond the bifurcation of the trachea. If too large a catheter is used, the return flow of air will be obstructed; if the catheter is introduced too far, it will partly or completely occlude the bronchus, and by pressure, destroy lung tissue. This possibility may be avoided by introducing it till it meets the bifurcation of the trachea, and then withdrawing it about an inch. A proper vaporizing apparatus, good light during the introduction of the catheter, and ordinary caution should prevent accidents. The greatest difficulty in this method of anæsthesia is the introduction of the catheter into the glottis. Because of this difficulty the method will never become a popular one. The only operations in which it may have an advantage over the intrapharyngeal method are pulmonary operations, with exposure of both lungs to atmospheric pressure, and intestinal obstruction, with more or less continuous vomiting.

Intravenous anæsthesia. Ether is soluble in physiological salt solution to the extent of 10.8 per cent by volume. For intravenous anæsthesia a 7 per cent solution may be used without producing laking of the blood or hæmoglobinuria. Sterile Ringer's solution may be used instead of salt solution. It should be kept at a temperature not above 80° F., because with the higher temperature the ether vaporizes and quickly escapes.

Anæsthesia can be obtained in two or three minutes, and transformed from a a light to a deep narcosis in a few seconds. About a pint of the solution is given per hour. When no premedication has been administered, the patient returns to consciousness about as quickly as with gas anæsthesia. The expired air contains an odor of ether in from forty seconds to a minute. Blood pressure is raised from 2 to 24 mm., but returns to normal in two or three hours.

The method originally adopted was that of interrupted flow; when anæsthesia was produced the injection was discontinued until the patient showed signs of returning consciousness. With this form of administration there is a tendency for the blood to coagulate at the point of the cannula, or for a thrombus to form in the vein. A greater amount may also be introduced into the blood than is required to produce narcosis. A better method is to give a weaker solution continuously, with graduation of the rate of the flowing stream. Kummel, in order to avoid thrombus formation, employed two tanks, one with normal saline and the other with ether solution, both being connected with stop-cocks and a Y-connection, so that when one solution was cut off the other continued to flow. This method was not altogether satisfactory, as the anæsthesia could not be kept at the same level. In 1912, Rood ([20]) devised a simple and efficient apparatus for maintaining a continuous flow, which could be accurately controlled and kept at a uniform temperature.

For injecting the solution a cannula is introduced and tied into a superficial vein, either the median basilic or cephalic of the arm farthest from the operator, or the internal saphenous at the internal malleolus. A needle of large caliber may be used instead of a cannula. The solution is rapidly introduced at first, the flow being diminished as narcosis develops. The usual signs of anæsthesia should be observed and the dose regulated accordingly. As with other forms of administration, an unobstructed air-way and efficient respiration must be maintained.

The advocates of the intravenous method of etherization contend that by introducing ether directly into the circulation a smaller amount is required to induce and maintain anæsthesia. In a comparison of the amount used to that used in the inhalation method, the fact that a considerable quantity is lost through evaporation and waste in the latter method should not be lost sight of. It has been shown experimentally that a certain ratio (15 per cent) between the blood and ether must be maintained, or the degree of narcosis will vary. As the amount of circulating fluid is increased by the saline solution used, the amount of ether must be increased in proportion to the increased volume of blood. It is claimed that this method is of special advantage in patients who are likely to be benefited by saline infusion, either because of hæmorrhage, shock, or low vitality.

Objections to the method are the possibility of local infection, the danger of septic thrombosis, and the occurrence of more profuse bleeding at the site of operation than when inhalation methods are employed. The possibility of pulmonary œdema during or following anæsthesia, the increase in blood pressure from the injection of a considerable quantity of fluid, and the difficulty of administration, both as to technique and apparatus, distinctly limit its field of usefulness.

Rectal anæsthesia. Sutton ([21]) in 1910 reported a series of 140 rectal anæsthesias. With one exception the patients were first anæsthetized by inhalation. Oxygen was used as a vehicle in 25; 12 received preliminary injection by morphine and scopolamine; 43 had at some time during the operation a supplementary administration by inhalation of chloroform or ether. Twelve belched gas from the stomach in the course of the anæsthesia, indicating a possible distention of the small intestines with regurgitation of the gas from the stomach; 43 cases vomited; 12 had abdominal distress; 5 had bloody stools or bloody fluid returned from the postanæsthetic enema. The most severe of the cases continued to pass blood for three days, during which time she vomited persistently. One case developed pneumonia.

Sutton says that "enough pressure must be exerted to distend to a moderate degree the entire colon, else the available absorbing surface will be too small. Too much pressure must not be exerted, lest by overdistention the vessels of the gut be flattened out, circulation impeded or abolished, absorption minimized, and the ischæmic mucosa left unprotected by its normal circulation to resist the effects of the ether." The method is contra-indicated in the presence of anal fistula, or any lesion of the intestinal tract such as ulcer, because of the danger of perforation. It is not used for laparotomies in general, because of the interference of the inflated colon with the surgical work. It cannot be used in emergency cases, because the lower bowel and colon must be free from all contents.

Buxton gives the following disadvantages of this method of narcosis: "Colicky pain in the intestine, urgent tenesmus, diarrhœa, sometimes dysenteric in character, painful distention of the intestinal tract, with more or less severe collapse."

This method of anæsthesia has never become popular, partly because of the frequent necessity of employing inhalation anæsthesia, due to the difficulty of maintaining a sufficiently profound narcosis. This objection makes it prohibitive in the very cases in which it has been recommended, i.e., operations about the head and neck.

Ether-oil colonic anæsthesia. The ether-oil colonic anæsthesia has many advantages over the ether-vapor rectal anæsthesia. Upon superficial observation the method is so simple that it has attracted the unwary. Upon close inspection, however, it is at once evident that it has not only distinct limitations but also distinct disadvantages. Adults are given one ounce of a 75 per cent solution of ether in olive oil for every twenty pounds of body-weight. Children are given a 50 or 60 per cent solution. The personal equation enters so largely into drug susceptibility that it would appear hazardous to attempt to figure the dosage on the basis of body-weight and age. Not to have the anæsthetic under immediate control in case of untoward accident, as, for example, in sudden severe hæmorrhage followed by shock, is a distinct disadvantage. We are told that if at any time the patient shows signs of a too profound anæsthesia, a portion of the mixture should be withdrawn. While this in itself is a simple procedure, the disorder occasioned by such necessity during a major operation must be considered. The injected solution may not remain in the lower bowel, especially if the operative requirements place the patient in the Trendelenburg position. If the mixture passes high in the colon or reaches the cæcum, the futility of an effort to recover it quickly through lavage is evident. Inasmuch as the ether is excreted principally by the lungs, if respiratory depression developes less ether is eliminated, while at the same time it continues to be absorbed from the rectal solution, still further depressing respiration. Another objection to the method is the inability to regulate the depth of narcosis to suit the operative requirements during the different stages of the operation.

Reports indicate that occasionally rectal irritation, which may prove quite distressing or end in death, follows this method of etherization. Dr. Gwathmey, the originator of the method, gives the following directions:

Castor oil is given the night before, followed in the morning by warm water enemas, one hour apart, until the return is clear. The patient may then be allowed to rest for two or three hours. One hour before the introduction of the ether mixture, 5 – 20 grains of chloretone in suppository, or dissolved in 4 drams of ether and mixed with an equal amount of olive oil, are given by rectum with the patient in the Sims position. For the chloretone, 2 – 4 drams of paraldehyde may be substituted in an equal amount of olive oil. Both the preliminary injection and the mixture should be administered very slowly through a funnel, which is attached to the end of a well lubricated catheter inserted four inches into the rectum. Twenty minutes before operation a hypodermic of 1/12 to 1/4 grains of morphine and 1/200 to 1/100 grains of atropine is given.

Adults are given a 75 per cent mixture of ether in olive oil. The size of the dose is reckoned upon a basis of one ounce of the mixture to every 20 lbs. of body weight, i.e., a man weighing 140 lbs. would need 7 oz. A 50 or 60 per cent solution is sufficient for children and weak anæmic adults. Eight ounces of the 75 per cent mixture will cause the anæsthesia to last from 2 to 3 hours. No more than eight ounces should ever be given, regardless of the patient's weight.

With the patient in the Sims position in his bed, the catheter is introduced about four inches into the rectum. The oil-ether mixture is then allowed to flow in, allowing at least one minute for each ounce. The patient quickly becomes drowsy. Ether appears on the breath in from three to four minutes. Excitement may be moderate or entirely absent. After from ten to thirty minutes, according to the absorptive power of the colonic mucous membrane, he may be placed on a stretcher and conveyed to the operating room.

The stage of maintenance is controlled by increasing or decreasing the freedom of the respiration, i.e., a towel over the face will prevent the escape of the ether vapor and, by inducing rebreathing of the expired ether, cause the patient to sink into deeper narcosis. On the other hand, an artificial air-way will lighten the anæsthesia by increasing the freedom of the respiration.

Occasionally it is necessary to supplant the rectal administration by the inhalation method with either ether or chloroform. If, on the other hand, the respiration shows signs of failure with cyanosis or stertor, the ether and oil injected should be immediately withdrawn, by reintroducing the catheter and allowing the retained solution to run off. In the event of failure of the respiration, rebreathing of carbon dioxide may be beneficial. If this should be ineffective, a vein may be opened and from 1,000 to 2,000 ccm. of normal saline injected with a hope of reducing the ether tension in anæsthetized tissue. When the operation is well under way, it has been found advisable to withdraw as much of the injection as may be reached with the catheter. At the completion of the operation a cold soapsuds enema is introduced high into the colon through one tube and drawn off through another. From two to four ounces of olive oil should be finally introduced with a view of neutralizing any ether which may remain unexcreted.

DEGREES AND STAGES OF ANÆSTHESIA

By carefully studying the effects produced by anæsthetics, it has been possible to speak of the depth, degree, or stage of the narcosis. In a general sense, three stages may be recognized: the stage of light anæsthesia, the stage of deep anæsthesia, and the stage of paralysis or death. The depth or degree of narcosis may be known by the pupillary reactions to light.

When patients have been given no hypnotic drug as a preliminary to anæsthesia, the pupillary reaction is the most valuable guide the administrator has as to the depth or degree of narcosis. Dilatation from operative stimuli is transient and need not be confounded with that produced by the anæsthetic. A dilated pupil which reacts quickly to light indicates a light anæsthesia. A dilated pupil which reacts slowly to light means a profound anæsthesia. A pupil which is widely dilated, and does not react to light, shows a dangerously deep anæsthesia and imminence of respiratory paralysis. A contracted pupil indicates a moderate degree of anæsthesia. In testing the pupillary reactions, the amount of light which strikes the pupil must be taken into account. Naturally, if the light is dull, the reaction will not be so active. When elevating the lid, the finger should be gently but firmly pressed close to the margin, and the lid suddenly raised. If the lid is slowly brought up and the narcosis very light, the reaction may be lost. When there is any resistance to manipulating the lid, the anæsthesia is very light,—too light for operative work.

The depth or degree of narcosis must correspond to the operative requirements. Different operations and different periods of the same operation require different degrees of anæsthesia. Generally speaking, patients in good condition may be safely kept in a state of deep narcosis. The rigidity due to a light anæsthesia in intra-abdominal operations is frequently a severe handicap to the surgeon, sometimes making the completion of the operation well-nigh impossible. Robust patients are more apt to exhibit reflex phenomena in response to intra-abdominal stimuli than weakly subjects. Manipulations within the upper part of the abdominal cavity have a tendency to bring about a characteristic expiratory "grunt." Manipulation in the neighborhood of the solar plexus, traction on the omentum, and similar procedures may cause sudden circulatory depression, the symptoms of which are likely to be erroneously referred to the anæsthetic.

RESPIRATION DURING ANÆSTHESIA

Provided the air channels are entirely patent, the entry and exit from the lungs may be completely noiseless during surgical anæsthesia. If the air-way be restricted, a too concentrated vapor administered, or an insufficient amount of oxygen allowed, respiration will increase in force and frequently become audible. The adventitious sounds which are produced in the upper air passages because of restricted respiration are distinct, and should not be confused with the modified breathing which is frequently present with a perfectly free air-way during abdominal operations. These adventitious sounds may occur during inspiration or expiration. The former are, as a rule, snoring, stertorous, or crowing; the latter strained, or phonated in character. Snoring is the most common adventitious sound, though by no means proportional to the degree of narcosis. It indicates a tendency toward an occlusion of the air-way, and when it becomes stertorous, is produced by the tongue either vibrating against the pharyngeal wall or occluding the pharyngeal channel. An engorged state of the tongue and adjacent parts contributes very materially to the production of stertor. While snoring and stertor are the expressions of a greater or less degree of obstruction above the larynx, stridor or a crowing sound indicates a spasm of the larynx itself, and is caused by a too concentrated vapor of ether or chloroform. The sound of mucus in the upper air passages cannot be confused with other adventitious sounds.

During anæsthesia the rate, depth, and regularity of respiration undergo important modifications, depending upon the character and location of the operation. Respiration is performed chiefly by the diaphragm during surgical anæsthesia, but in young children it may be purely thoracic, being effected principally by the intercostal muscles, unless some impediment to the free entry of air takes place tending to make it diaphragmatic and jerky in character. In the conscious patient, respiration is a more passive process than in the anæsthetized subject, where the recti and other abdominal muscles often take part in its performance. Any hindrance to free thoracic or abdominal movements, such as tight clothing, bandages, certain postures, or the weight of assistants' arms, may introduce an asphyxial element. In edentulous persons, especially if nasal obstruction is present, the lips may be sucked in and act as a valve, permitting expiration but hindering inspiration.

As the diaphragm is the most important muscle of respiration, it is desirable that its descent should not be impeded, especially in those subjects in which the thorax is unable to take on additional work. It is also important to provide for free thoracic expansion, particularly if the abdominal movements are suspended. Feeble patients, fleshy patients, or those who are emphysematous or have fluid in their chest, should be carefully watched, as the mechanical interference with breathing may cause serious accidents. Respiratory embarrassment may be caused by the lithotomy position and the extreme Trendelenburg position, especially in the latter if the abdominal contents are crowded against the diaphragm with sponges. Lung expansion may be limited by postures in which the weight of the trunk is expended directly on the chest, as in the prone or semiprone position. When the operative procedure requires this position, as in laminectomy or in operations upon the cerebellum, an endeavor should be made to facilitate lung expansion by placing sand bags under each shoulder and each iliac spine. If breathing becomes much embarrassed, the patient should at once be changed to the dorsal position.

By the careful observation of symptoms, i.e., watching for the slightest deviation from what may be called the normal course, and by correcting or relieving symptoms which are in themselves but trifling, it is often possible to avert respiratory arrest on the one hand or circulatory failure on the other. The character of the breathing will depend upon a number of factors. The local action of a too concentrated vapor during the induction period may induce coughing, holding the breath, or laryngeal spasm. Nitrous oxide administration with a deficiency of oxygen will lead to exaggerated breathing, stertor, deep cyanosis, clonic spasms, and finally death from asphyxiation. When rebreathing is practised, hyperpnœa is always present to a greater or less degree, depending upon the amount of carbon dioxide which the patient is made to reinhale. Crying children are likely to inhale large quantities of the anæsthetic, and in the administration of chloroform great care must be exercised to allow an abundance of air, or respiratory paralysis may ensue. With the administration of nitrous oxide they may quickly reach an undesirable degree of asphyxia. Coughing during the induction period indicates a too concentrated vapor. Retching and vomiting during the induction period are rare if the patient has been properly prepared; and when they occur later in the narcosis, they always mean a light anæsthesia. A localized or general tremor occasionally occurs under chloroform, but is more common under ether. As a rule it may be controlled by changing the position of the limbs or increasing the depth of narcosis.

One of the foremost responsibilities of the anæsthetist during the maintenance of anæsthesia is to recognize and eliminate all the factors which tend to produce even slight degrees of anoxæmia. Special attention must be paid to the patency of the upper respiratory channels through which the anæsthetic vapors or gases must pass. It is impossible to overestimate the importance of maintaining a clear air-way. A higher level of safety to the patient will be attained if an adequate amount of oxygen gains access to the system throughout the narcosis, because the respiratory center in the medulla is depressed by an anoxæmia, particularly if it is sufficient to produce cyanosis either in the acute form or by gradual process. Not only is the respiratory center depressed if the blood is in a condition of anoxæmia, but cardiac dilatation and paralysis are much more apt to occur if the coronary vessels which nourish the heart are filled with venous blood. Except in pure gas anæsthesia, convulsions or clonic muscular movements are rare, and are not to be expected during an asphyxial death when ether or chloroform is being administered. Muscular rigidity, when accompanied by cyanosis, calls for more oxygen and less of the anæsthetic.

Types of breathing during anæsthesia. All kinds of breathing are met with during anæsthesia, from the deep respiration of the strong patient to the feeble and almost imperceptible breathing of the very ill and fragile child. Moreover, the respiration varies from time to time in the same patient, depending upon the character of the operation, the degree of manipulation of the tissues, the method of administration of the anæsthetic, and the depth of narcosis.

Rapid breathing during the induction of anæsthesia is a voluntary effort due either to nervousness or a desire to lose consciousness quickly, but when it appears during surgical anæsthesia it is usually associated with a hyperpnœic condition and calls for more oxygen or air. If it develops during light anæsthesia, it is caused by stimulation of the afferent nerves by the operation and will be corrected by a more profound narcosis. It is occasionally seen in pyrexia, in which case it is not affected by the anæsthetic.

Deep breathing usually indicates surgical anæsthesia, and as long as it proceeds regularly without exaggerated chest movements, it is the most desirable and safest type of respiration. When the accessory muscles of respiration are called into action, an asphyxial factor is present, and the exaggerated thoracic and abdominal movements are an effort on the part of the respiratory system to obtain more oxygen. Forcible deep breathing during surgical anæsthesia frequently occurs when the sphincter, urethra, or cervix are dilated, or the spermatic cord is dragged upon, or diseased large joints manipulated.

Shallow breathing before consciousness is lost is a voluntary effort to keep from inhaling the anæsthetic. This form of breathing is rarely seen when nitrous oxide and oxygen are being administered; it is occasionally present with chloroform, and not infrequently observed with ether, especially if the latter is given in a concentrated form. With the open method of etherization, the concentration can be controlled to such a nicety that the odor is seldom complained of and respiration is normal throughout the induction period. If breathing is superficial, the induction period is lengthened, due to the anæsthetic entering only the trachea and larger bronchi, where the area of absorption is very limited. Patients who have had morphine, or any of the opium derivatives, are apt to exhibit slow respiration. When consciousness is lost, shallow breathing indicates either a light narcosis with impending vomiting, or a profound anæsthesia with approaching respiratory paralysis. If breathing is shallow, or the patient holds his breath during the induction period, the vapor should be made less concentrated and the patient encouraged to breathe naturally. If vomiting is present and the vomitus shows undigested food, it is wise to allow complete emptying of the stomach; otherwise a smooth anæsthesia is frequently impossible. On the other hand, if the stomach is free of solid food and there is nausea and an effort to expel liquid contents, a deeper narcosis will paralyze the vomiting center. If shallow breathing develops and the evidence indicates a profound narcosis, the anæsthetic must be withheld; and if deeper breathing does not soon develop, respiration may be assisted by compression of the thorax during expiration. If such compression is suddenly released, the elasticity of the chest walls assists deeper breathing. This simple procedure will encourage automatic breathing and the elimination of the anæsthetic. Shallow breathing is more apt to occur under chloroform than ether narcosis, and when any of the opium derivatives have been administered. In the latter case, it is much more difficult to control than when the depression is due to the anæsthetic alone.

Irregular breathing except during early anæsthesia is of very grave significance, and is always a sign of impending central respiratory paralysis caused by an overdose of the anæsthetic. The administration should be suspended and a clear air-way maintained. If, in spite of these measures, breathing ceases, artificial respiration must be performed. Irregular breathing during light anæsthesia gives no occasion for alarm, and can be controlled by the administration of more anæsthetic.

The presence of an anoxæmic factor may be observed in the lack of oxygenation of the blood and congestion of the venous system with undue oozing from the operation wound, and by the bluish color of the ears, lips, and cheeks. When anoxæmia is present, there is prone to be a congestion of the mucous surfaces of the respiratory tract, tonsils, tongue, and neighboring structures, and this engorgement further aggravates the condition by presenting a mechanical obstruction to the ingress of the air. There is an increased amount of mucus secreted by the congested surface, which still further adds to the anoxæmia. This condition is very markedly aggravated if the Trendelenburg position is assumed, particularly if the subject is fleshy. The more nearly an anæsthesia approaches normal sleep, the more ideal it becomes. When the proper technique of the open method of etherization is employed, this most desirable state, in a very large majority of cases, prevails throughout the narcosis.

Coughing, straining, or any embarrassment of respiration will produce more or less venous turgescence, with a resulting increase in the bleeding at the field of operation. Generally speaking, ether leads to a greater vascularity than chloroform, but when administered with an abundance of air or oxygen, and with no interference to respiration, after the first ten or fifteen minutes there is but little difference in the two anæsthetics.

When the closed or rebreathing methods are used, the character of the breathing and oxygenation of the blood are affected by the amount of oxygen or air allowed and the quantity of anæsthetic given. If a large amount of ether is poured in at once, the respiration usually becomes slow and superficial, and may be irregular in rhythm. When small quantities are given at short intervals, the breathing is less affected.

Breathing during the stage of recovery. When no hypnotics have been given, the breathing during the return to consciousness is normal in rate, depth, and regularity, unless it is temporarily disturbed by vomiting. If narcotics have been administered before the narcosis, irregular or shallow breathing may develop, or respiratory cessation may occur after the administration has been suspended for some time. Recovery from the anæsthetic will be prolonged if tight bandaging prevents full lung expansion, or if respiration be hampered in any way. Patients should be watched till sufficiently awake to cough or clear their throats of vomited matter without assistance. The posture of patients recovering from narcosis, particularly those who are suffering with empyema or lung affections, is important, as they are in a state of more or less anoxæmia at the time from respiratory difficulty. In order to allow of the free excursion of the healthy lung, the affected side should be underneath.

METHODS FOR THE RELIEF OF RESPIRATORY ARREST

Suspension of respiration during ether or nitrous oxide administration is not nearly so dangerous as when chloroform has been given. The continued absorption of the inhaled chloroform will readily destroy life. The important point concerning respiratory failure under ether is that, however such failure may arise, the circulation at the moment is usually sufficiently satisfactory for remedial measures to prove successful. Should the administration of ether or chloroform be carried too far, respiration will show signs of depression some time before actual cessation occurs. In some cases the breathing assumes a modified Cheyne-Stokes character. In the majority of instances, however, it becomes more and more feeble, and then ceases. Occasionally jerky, intermittent, and gasping breathing may precede cessation. The color becomes dusky rather than pale, the pulse less forcible and usually slower.

Many anæsthetists have appliances and remedies at hand for use in case of respiratory or circulatory depression. It is far better and much more satisfactory to prevent complications than to combat them after their development. The first step for the relief of respiratory arrest is to establish a clear air-way. A mouth gag should be inserted and the finger swept around the mouth and back in the pharynx to remove any foreign substance. With a piece of gauze over the thumb and forefinger, the tongue is grasped and drawn forward out of the mouth. By exerting regular pressure on the lower part of the sternum with the hand at intervals of a few seconds, the elastic recoil of the chest is brought into play, and the lungs permitted to refill with air (Howard method).

Intrapharyngeal and intratracheal insufflation. The technique is identical with that used in these methods of anæsthesia, except that air or oxygen is forced into the lungs instead of an anæsthetic, and that it is administered intermittently if the intratracheal method is used. Care must be taken not to overdistend the lungs, or a rupture of the air vesicles will result. The pressure should not exceed 30 mm. An ordinary foot bellows or an electric vaporizer may be used to deliver air or oxygen through the tube to the lungs. Intrapharyngeal insufflation is more easily and quickly carried out, because, in the hands of the inexperienced, valuable time may be lost in introducing the catheter into the trachea; on the other hand, it is not quite so satisfactory because of the difficulty of preventing the escape of the air or oxygen through the mouth or nose, or its entry into the stomach. The lips may be held or fastened together by adhesive plaster; the nasal tubes, combined with pressure, will prevent the escape of air in that direction. A heavy weight or deep pressure over the stomach will keep the air from entering that organ, and by forcing the blood out of the splanchnic area into the general circulation, send more blood to the respiratory and circulatory centers. In very young infants mouth-to-mouth breathing has been suggested. In threatened respiratory arrest, rhythmic compression of the chest wall may be effective in stimulating respiration. This method is especially valuable in young individuals, whose thoracic parietes possess much resiliency, and usually answers as well as any method of resuscitation in the milder forms of respiratory depression. It is a mistake, even during such an exciting and serious moment, to place a forceps on the tongue, because of the after-suffering such a mutilating practice inflicts.

Sylvester method of artificial respiration. With the patient lying flat on his back, the head lowered and extended backward, the mouth is held open with a mouth gag, and the tongue held out to insure a free air-way. With the operator standing above the head, the arms are grasped above the elbows, and by a forward movement are made to compress the chest wall and cause a strong expiration. The arms are then drawn outward and upward till the hands meet above the head: this manœuvre causes deep inspiration by reason of the traction exerted upon the accessory muscles of respiration. These movements are repeated regularly about fifteen times a minute or at the rate of normal respiration, until natural automatic breathing is established. Care must be taken not to press too firmly on the chest wall, as there is danger of fracturing the ribs.

POSTURE, CHANGE OF POSTURE, THE TRANSFERENCE OF UNCONSCIOUS PATIENTS

The posture of patients during general surgical anæsthesia is a matter of greater importance than is generally imagined. Flexion of the head throws the base of the tongue against the pharynx and obstructs breathing. Extension carries the epiglottis away from the glottis, thus exposing the larynx to the entry of foreign substances. Turning the head to the side prevents the tongue from falling back in the pharynx and obstructing respiration, and allows the mucus to pass out of the mouth instead of running back in the trachea and causing coughing. For tonsil and adenoid operations, the lateral posture is desirable, as it is least likely to be associated with any respiratory embarrassment from the presence of blood. Anæsthesia may be induced in the dorsal position and the patient changed to the lateral after narcosis is established. When the prone posture is necessary, as it is for such operations as laminectomy and for cerebellar tumors, an endeavor should be made to avoid respiratory embarrassment by placing sand bags under each shoulder. Breathing must be watched if a change in posture becomes necessary. Mucus and saliva may trickle or flow from one part of the upper air-tract to another causing coughing or vomiting, or the tongue may fall back in the pharynx and obstruct respiration. Cyanosis with other asphyxial phenomena are more apt to follow a change in posture during light than deep anæsthesia, while syncope is more likely to develop during the narcosis if the patient be raised from the horizontal into the sitting posture. This danger is especially great if chloroform has been given. In bandaging the chest or abdomen, the patient, if an infant, can be lifted from the operating table and kept horizontal, while adults can be brought over the end of the table and so held, with the head on a level with the body.

For reasons already given, it is most desirable that patients should be anæsthetized upon the table to be used during the operation, and not in their beds or upon carts. It is especially hazardous to transfer those suffering with respiratory or circulatory affections.

Posture paralysis. Nerve roots or nerves themselves may be so compressed or stretched that paralysis in varying degrees may result. The most common posture paralysis is the one which occurs after long operations, during which time the arm has been abducted and drawn upward. If the hand is allowed to hang over the side of the table, the musculospiral nerve may become compressed between the humerus and the table edge with a resulting paralysis. The application of an Esmarch bandage may induce a temporary motor or sensory paralysis. Complete recovery from these various posture paralyses generally takes place within a few weeks or months; however, it may be delayed as long as a year. Recovery usually takes place from the periphery towards the center.

After-care of patients. After the completion of the operation, all wet or soiled clothing should be removed, a warm, dry gown put on, and the patient well covered with woolen blankets for the journey back to his room. The bed to which the patient is to be transferred should be warmed by means of hot bottles, which should be removed before the patient is placed in it. A large number of cases have occurred in which hot water bottles have produced burns during the unconsciousness of the recovery period.

The practice of washing out the stomach after anæsthesia in order to eliminate any secreted ether is of questionable benefit. This procedure, however, is of distinct value in patients suffering with intestinal obstruction when fæcal vomiting is present.

NAUSEA AND VOMITING

Long and persistent vomiting after operation prevents the taking of food, and entails so much discomfort and exhaustion on weakly subjects that the importance of its consideration is obvious. An effort should be made to ascertain the cause of vomiting, and to select remedies accordingly. The anæsthetic may be the sole cause, may be only a contributing factor, or not at all responsible; therefore, the expression postanæsthetic vomiting, while literally correct, conveys the wrong impression.

Provided the patient has been properly prepared, the administration skillfully conducted and pure anæsthetic used, there will be no trouble from nausea and vomiting during the induction of narcosis. Vomiting during maintenance occurs only when a light anæsthesia is present, and the medullary center is irritated, but not narcotized. Transient retching with the expulsion of a yellowish fluid may develop after the anæsthesia is discontinued, while the patient is still unconscious. This is an advantage, as it clears the upper air passages of mucus, and the stomach of fluid and any anæsthetic which may have been excreted into it. Vomiting following throat and mouth operations is desirable and to be expected on account of the blood which may have entered the stomach during the operative procedures, or been swallowed during returning consciousness. Vomiting following anæsthesia is much less common in children than in adults; if it persists, acidosis should be considered, and the urine examined for acetone and diacetic acid. This is especially important if chloroform has been administered.

Nitrous oxide-oxygen is least likely to be followed by nausea and vomiting. Transient vomiting is more common following ethyl chloride and ether anæsthesia than chloroform; but persistent vomiting is more frequent after chloroform. Uneven or intermittent administration, with an insufficient amount of oxygen to keep the blood well oxygenated, increases the tendency to vomit.

After mouth, jaw, and throat operations, a considerable quantity of water, to which bicarbonate of soda has been added, will assist in clearing the stomach of swallowed blood or pus through emesis, or by washing the contents into the bowel. If food or drink is allowed too soon after operation, it may cause vomiting when none has existed before. The persistent vomiting of acidosis is relieved only by measures employed to combat the acid poisoning—bicarbonate of soda per rectum, or intravenously in desperate cases. Fæcal vomiting ceases only when the obstruction which caused it is removed. If there is atonic distention, strychnine or pituitary extract, given hypodermatically, are often effective. With persistent vomiting, due to gastric dilatation or decomposition of stomach contents, gastric lavage is usually followed by prompt relief.

Hare says that one of the most efficient internal remedies is acetanilid, given in one or two grain doses, every fifteen minutes or half hour, until eight grains are taken. It may be given in brandy in teaspoonful doses poured over shaved ice, or it may be placed as a dry powder on the tongue.

When vomiting is due wholly to ether, olive oil introduced into the rectum, as suggested by Graham, is of undoubted value. The unconscious patient who is vomiting should have his head kept turned to the side, and the opposite shoulder raised. Unless such patients are well attended there is danger of suffocation or aspiration of vomitus into the trachea.

LUNG COMPLICATIONS FOLLOWING OPERATION

Clinical reports indicate that with the possible exception of mouth and throat operations, lung complications most frequently follow abdominal operations, especially stomach, gall-bladder, and pelvic work, with carcinoma of the stomach furnishing the largest mortality, regardless of the nature of the operation. Aspiration from the mouth or pharynx of foreign substances, both solid and liquid, weak heart action with low blood pressure producing hypostatic congestions, cooling of the body surface, diminished lung expansion, morphine, which allays the reflex excitability of the air passages and thereby favors the retention of aspirated materials, all contribute their quota to lung complications. Undoubtedly many of them are secondary to some pre-existing bronchial or lung affection, the effects of the anæsthetic being secondary. In 35 of the 55 cases reported by Armstrong ([22]) a septic focus in some part of the body was present before the development of the lung complication. That the anæsthetic is by no means the only factor is shown by the not uncommon occurrence of pneumonia following operations under local anæsthesia.

The so-called "ether pneumonia" is frequently a lobar-pneumonia, due to emboli which have entered the circulation at the site of operation. The time at which the symptoms develop varies from a few hours to a week or more. They are sudden in their onset, with pain in the chest, temperature, cough, and quick respiration and pulse. As a rule, constitutional disturbance is not great. Homans ([23]) reports the consolidation of an entire lobe, following pulmonary embolic infarction. Fractures of the long bones are occasionally followed by fat emboli which produce infarcts of the lungs, the symptoms of which are clinically so similar to pneumonia that it is sometimes difficult to differentiate the two.

That ether is most likely to produce respiratory effects is questionable, particularly when it has been properly administered. The dreaded "mucus inundation," so frequently discussed by English authors, is certainly rarely witnessed in a properly conducted open administration. A too concentrated vapor during early induction is responsible for the large majority of such accompaniments. The rule should be followed, whenever practicable, of keeping the patient's head turned to the side for the escape of mucus or saliva. If in spite of this, there is an accumulation sufficient to produce cyanosis and audible rattling with labored breathing, the administration should be suspended until the faucial reflexes return, and coughing or vomiting clears the air passages. If the anæsthetic is then continued and a light vapor administered, no further trouble will be experienced.

In addition to the factors already mentioned, others doubtless come into play, such as excessive air limitation during etherization and the adoption of a peculiar position for a protracted period after anæsthesia, so that mucus plugging and hypostatic congestion are favored. Patients who have painful abdominal wounds refrain from deep breathing and coughing, which tendency favors basic engorgement of the lung and the retention in the bronchi of blood, septic matter, or vomitus which may have passed into the larynx. The use of imperfectly cleansed inhalers favors the occurrence of lung complications. Postoperative pneumonia may be caused by bacteria or their toxins, carried through the lymph or blood stream after operations on infected tissue, or by exacerbations of pre-existing focal infections. Lung abscesses following tonsil and adenoid operations are held by some observers to be embolic in their origin, but the aspiration of septic material directly through the air passages into the alveoli is a much more probable cause.

Preventive treatment of respiratory complications following operation is an exceedingly important matter. Aseptic technique and minimum traumation to the tissues during operation decrease the possibility of embolism and thrombosis. When ether is the anæsthetic of choice, the open method of administration should be used, allowing as much air as is consistent with narcosis and an even administration. The anæsthesia should be as light and short as possible. No solid food should be allowed for at least six hours before operation. The stomach contents should be aspirated in emergency operations. The mouth, teeth, and throat should be disinfected as far as possible with a mild wash containing alcohol. The head should be kept turned to the side to allow mucus to escape and prevent the aspiration of vomitus. The operating table should be covered by thick, dry pads and the patient by blankets to prevent loss of body heat, both during the operation and when being conveyed through halls and elevator shafts.

Respiration should not be hampered by tight bandages or unrelieved pain following abdominal operations, as the normal descent of the diaphragm is inhibited, interfering with pulmonary ventilation, coughing, and expectoration.

In mouth, jaw, and throat operations, an early awakening from the anæsthetic is desirable, so that a semi-recumbent or sitting posture may be assumed to assist in clearing the bronchi of aspirated blood or pus.

KIDNEY FUNCTION UNDER ANÆSTHESIA

It is desirable that patients suffering with nephritis should not be profoundly anæsthetized, that a concentrated vapor should be avoided, and that the administration should be as short as possible. During deep and prolonged narcosis the kidney function is considerably lessened or altogether suspended, but it returns as soon as the patient begins to awaken, and attains its maximum intensity in the course of three or four hours after the close of the administration.

Ether as a causative factor in nephritis has been greatly exaggerated. Buxton and Levy ([24]) found that with ether and chloroform no albumen occurred in 94.6 per cent of human patients, and in 5.4 per cent a trace of albumen was found which rapidly disappeared. There may be frequently an associated kidney involvement in focal infections. The author has often anæsthetized patients with albuminuria whose urine cleared up after tonsillectomy. Nephritis following operation on infected tissue may also be hæmatogenous in its origin. Hogan ([25]) says, "The chemical effect of the anæsthetic upon the chemistry of the whole body evidences itself in certain qualitative and quantitative changes. There is, for example, an increased hydrogen-ion concentration observable on examining the urine, and a diminished chloride output. At the same time incompletely oxidized bodies, as acetone and diacetic acid, may be found. If the resultant acid intoxication is severe, albumen and casts appear in the urine and an increased ammonia elimination may be observed. The presence of acetone and diacetic acid means that carbohydrate and fat metabolism has been so upset that they are not completely oxidized, as normally, into carbon dioxide and water. The retention of chlorides by the tissues goes hand in hand with increased acidity and is due to this acidity. An increase in the acid content of a tissue not only leads to a retention of water and œdema, but to a retention of certain salts at the same time.

"These conditions show that urinary secretion is possible only when free water circulating in the blood is brought to the kidney, and that an anæsthetic produces the effects it does because it leads to a lack of oxygen in the tissues of the body. This raises their acid content, and makes them absorb more water from the blood, which in its turn diminishes in that proportion the amount available for secretion. The kidney secretion diminishes, not because of a specific poisonous effect upon the kidney alone, but because of this effect upon all the tissues and organs of the body. The postoperative symptoms of nausea, vomiting, headache, and gas pains parallel completely in their intensity the intensity of the changes noted in the urine."

This author suggests the feeding of carbohydrates and the use of water, alkalki, and salt at least two or three days before operation; it should be continued until the patient has a urine persistently neutral to litmus. A patient with a highly acid urine, with a high ammonia coefficient, or with acetone and diacetic acid in his urine is a bad surgical risk. Patients properly prepared recover rapidly from the effects of the anæsthesia. They are without headache and vomit little because of absence of œdema of the brain; they urinate promptly after the operation, because of the absence of kidney œdema and the early presence of free water; their urine is practically free from albumen and casts, and excess of ammonia.

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CHAPTER II

NITROUS OXIDE-OXYGEN ANÆSTHESIA

TECHNICALLY, nitrous oxide-oxygen is the most difficult of all anæsthetics to administer safely. When administered by a trained anæsthetist it is the safest of all anæsthetics. It is quick in its action and is pleasant to take. It produces but slight nausea; it is almost a specific against shock. Recovery from the anæsthetic is almost immediate. In military surgery it was designated as the anæsthetic of choice by the Interallied Surgical Conference.

No other anæsthetic has such a wide range of usefulness. In minor operations, or for operations upon bad risks, in exophthalmic goiter in particular, in which complete anæsthesia will increase the danger, nitrous oxide analgesia abolishes pain, while consciousness is retained.

It should always be borne in mind that in no other form of anæsthesia is attention to detail so necessary, or exact observance of the minutiæ so essential to a perfect anæsthesia.

TECHNIQUE OF ADMINISTRATION

With the exception of the aged, the young, and the most seriously ill, the patient receives a pre-anæsthetic dose of morphine and scopolamine. To induce anæsthesia the index valve from the mixing chamber to the face-inhaler is opened to the point which will give analgesia. The mask is first held over the face and then gradually lowered. As hearing and the pressure sense are exaggerated, the operating room should be quiet. If restraint is necessary, it should be as gentle as possible. While analgesia is being established, the anæsthetist can begin to adjust the mask, as shown in Figure 3. The towel which holds the mask is folded lengthwise, and placed under the nape of the neck. The mask should be held firmly in place, with the chin well forward. The exhaling valve should be left open, as the sense of pressure is uncomfortable. The respiration and color should be watched, so that at the first indication of cyanosis the oxygen port may be opened a little wider. With the face mask properly adjusted, the anæsthetic mixture is increased to the amount that in the average patient will produce anæsthesia.

The first fifteen minutes are the most critical time in the establishment of any type of anæsthesia, and this is particularly true of nitrous

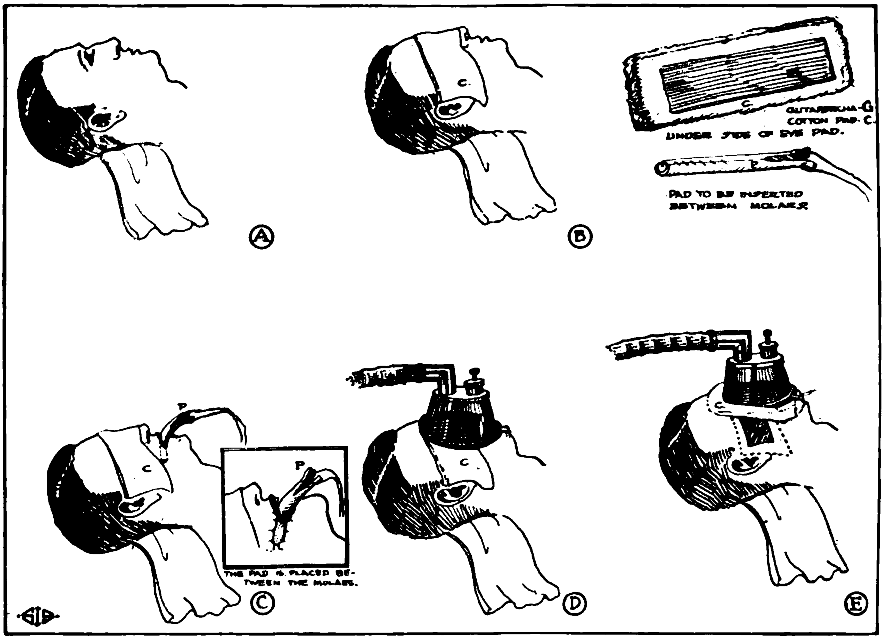
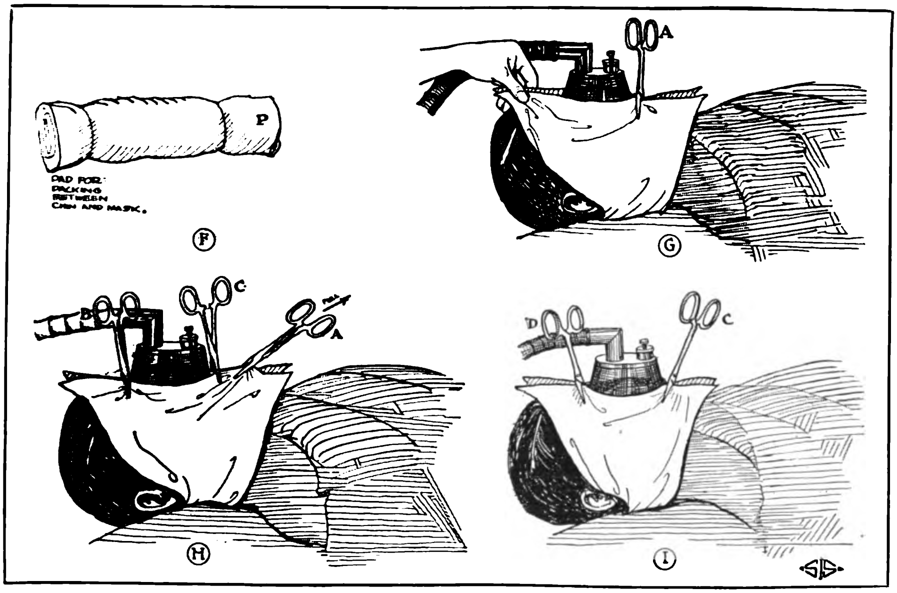


FIG. 3.

oxide and oxygen. Too rapid an induction means oversaturation, resulting in a disagreeable state of asphyxiation with its attendant clonic or tonic spasm and rigid abdominal muscles. The tendency is to remedy this condition by giving pure oxygen, thus bringing the patient into too light a stage of anæsthesia. Such a sequence may usually be avoided by careful induction.

The dosage of the gases is always regulated by the clinical signs of anæsthesia. Female patients of average size and type require 60 – 100 gallons of nitrous oxide per hour, with 20 – 25 per cent of oxygen; male patients require 80 – 115 gallons of nitrous oxide per hour, and the same percentage of oxygen. After the first hour it is usually possible to reduce the amount of nitrous oxide and oxygen. If the patient is resistant, ether vapor may be added to secure tranquility and safety. With alcoholics this is generally necessary. The amount required may be only an occasional whiff, or it may be necessary to add a definite percentage of ether vapor.

With patients who show a quick response to nitrous oxide, or a slow response to oxygen, it is usually best to increase the nitrous oxide carefully; the addition of a small percentage of ether makes a safer



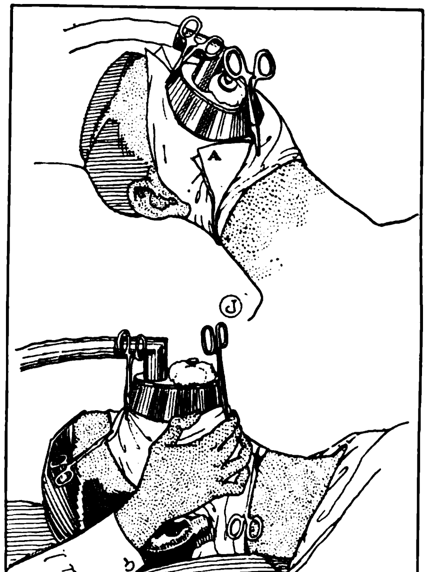


FIG. 3. STEPS IN THE ADJUSTMENT OF FACE MASK. *a,* Patient's head in proper position. *b,* Guttapercha covering over the eyes with cotton pad on top, eye covering, and cotton dental prop. *c,* Cotton mouth prop in position between the molars. *d,* Mask in position, ready to adjust cotton packing. *e,* Cotton packing adjusted around the face mask. *f,* Cotton pad covered with gauze to be used between the mask and chin. *g,* Towel folded in straight line, to meet the upper edge of the rubber cushion on each side of the mask. *h,* Mask tightened by re-adjusting the hemostats. *i,* Mask in position. *j,* Folding in of the ends of the towel to support the chin. *k,* Mask in position.

mixture. By a slow induction, however, it is often possible to establish anæsthesia with nitrous oxide and oxygen alone, even in difficult cases. Securing additional relaxation during the course of the operation usually takes from three to four minutes. If it is necessary to increase the percentage of ether vapor to secure relaxation, it is best to decrease the nitrous oxide for the time. If ether complications such as mucus or laryngeai spasm arise, it is best to change back to nitrous oxide and oxygen for a few moments and then give the ether vapor more slowly. After relaxation is secured it can usually be held by nitrous oxide and oxygen, with occasional whiffs of ether.

As the anæsthesia proceeds, the problem becomes more simple; usually the nitrous oxide dosage does not need to be changed except in response to increased trauma in the operation. The patient's face must be carefully watched and cyanosis overcome quickly. The color is the best clinical guide as to the proper oxygen content. The expression of the face under ether is one of profound narcosis; under nitrous oxide, the face appears as in normal sleep. The eyes are quiet and the pupillary reflex to light, as seen in ether anæsthesia, is absent.

The chief danger of nitrous oxide and oxygen anæsthesia is asphyxiation. Without admixture of oxygen, nitrous oxide will not support life. Failure to respond to oxygen usually means the presence of some mechanical obstruction. If this occurs, the face mask is removed, a breathing tube inserted, and the mask quickly readjusted.

Rebreathing is a very useful adjunct in stimulating or deepening a shallow respiration, but too much carbon dioxide should be avoided, as it leads to overstimulation of the respiration, and consequent fatigue and exhaustion of the respiratory muscles. Excessive stimulation may also lead to the oversecretion of mucus, and vomiting. If this occurs, the volume of the fresh nitrous oxide and oxygen must be increased and rebreathing discontinued. Stimulation may progress so far that ether vapor may be necessary, but it is better not to allow the condition to reach this point.

Positive pressure is obtained by the use of a tight-fitting face mask, and by screwing down the exhaling valve so as to prevent the escape of the expired air. This manœuver brings into play an increased dosage of carbon dioxide, which is taken care of by releasing the exhaling valve from time to time. Positive pressure is a valuable adjunct in cases of obstructive goiter, with partial collapse of the trachea.

Analgesia. The development of the use of analgesia with nitrous oxide and oxygen has proved most interesting and valuable. The selection of the patient, and the character of the pain are important considerations. Deep pressure, pulling, and retracting quickly produce an appreciation of pain, which is sometimes hard to control. From 10 to 45 gallons of nitrous oxide per hour, with about 25 per cent of oxygen, are sufficient to produce analgesia. The face mask must be adjusted comfortably and the exhaling valve released. It is best to impress on the patient the fact that he will hear the anæsthetist or the surgeon speaking to him, and that he will feel contacts, but will not feel pain. The expression of the face should be closely watched, and if a change of expression indicates the presence of pain, the nitrous oxide content should be increased for a few breaths. During analgesia the pressure sense is exaggerated; if the patient moves, it is wise not to hold him tightly, but rather to move with him, suggesting what position is desired. The sense of hearing usually remains, but slow response to questions is often noted, and the voice may be slightly thickened. The respiratory rate should not be increased above normal. The expression of the face should be placid, and the pulse rate regular. If analgesia does not prove sufficient to cover the operative procedure, the patient is quickly put under anæsthesia.

Analgesia is especially useful for the opening of abscesses and for other minor work, particularly when the patient wants to go home immediately after the operation. In bad operative risks it is combined with local anæsthesia. It is of great value in ligations for exophthalmic goiter, and, when possible, for thyroidectomies on severe cases.

Accurate knowledge and care of the anæsthetic apparatus, the pressure gauges, and the tanks are absolute requirements. There are on the market today some excellent forms of apparatus, fully described by Gwathmey in his noteworthy book. In the Lakeside clinic the Ohio monovalve apparatus is principally used because it permits the use of gases at a low pressure.

Nitrous oxide may be purchased in large cylinders or manufactured at the hospital and piped to the operating rooms from the generating room (Fig. 4a). A uniform pressure of five pounds may be maintained by means of pressure gauges attached to the gas holders. To a hospital contemplating the use of gas as routine, it would be of great advantage to have such a system installed. Large cylinders, however, containing 3,200 gallons of nitrous oxide or 1,150 gallons of oxygen, to which are attached duplex reducing gauges and rubber tubes connecting the cylinders with the machine, constitute an efficient arrangement (Fig. 4b). The gas machine should also be provided with small cylinders, so that if the supply in the large tanks runs out, the anæsthetist can quickly change to the small tanks. For work in private houses or small hospitals a small portable machine is required, equipped with cylinders containing one hundred gallons of nitrous oxide or forty gallons of oxygen.

The care of the pressure gauges is an important matter, and it is necessary to follow carefully the directions of the manufacturers with reference to their use. An electric heater should be applied to the nitrous oxide valve when either the small or large cylinders are in use, to prevent the valve from freezing and thus hindering the flow of gas. At regular intervals all rubber tubing should be carefully examined for leaks. The machines should be kept absolutely clean with soap and water. In our clinic the face masks and breathing tubes are washed after each case, rinsed thoroughly, put in a 1-40 carbolic solution, rinsed again, and thoroughly dried. After a septic case the whole machine is disinfected, and the bags and tubes boiled. The celluloid face inhaler is thoroughly washed and left to soak over night in a 1-20 carbolic solution. Cultures are taken as a routine of all gas machines in use, and the results recorded.

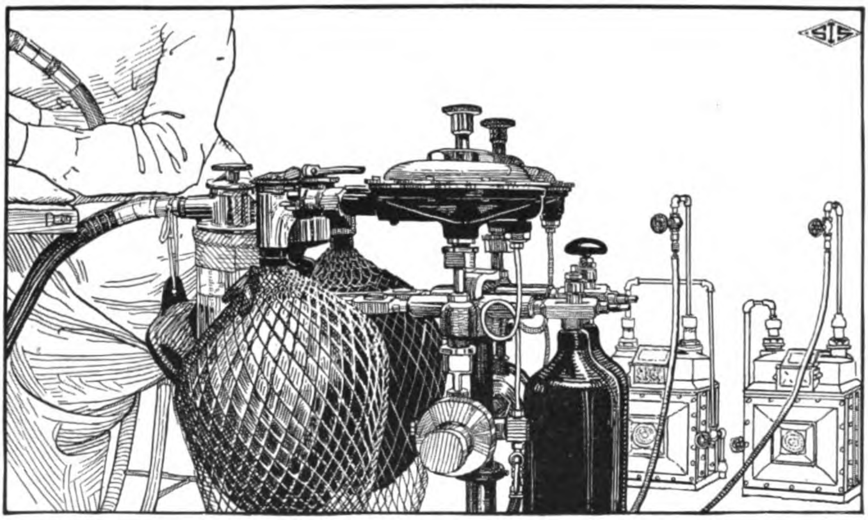


FIG. 4a. OPERATING-ROOM ARRANGEMENT OF NITROUS OXIDE-OXYGEN APPARATUS AT LAKESIDE HOSPITAL.

TECHNIQUE FOR SPECIAL OPERATIONS

Abdominal operations. Since nitrous oxide does not give so much muscular relaxation as ether, relaxation must be obtained by special methods.

If a local anæsthetic is used in conjunction with nitrous oxide and oxygen, muscular rigidity is greatly diminished, but even with this combination certain patients cannot be sufficiently relaxed without the addition of ether vapor. It is important, therefore, in selecting a machine for general surgical work, to make sure that the ether attachment will deliver sufficient ether vapor to produce the necessary surgical relaxation under any condition. Relaxation depends not upon the amount of anæsthetic given after the saturation point is reached, but rather upon the evenness with which the anæsthetic is administered. The importance of maintaining a free passage for the gases as well cannot be overestimated.

It is essential that the patient be well anæsthetized before the operation is started. If relaxation is properly secured early in the anæsthesia, it can be held remarkably well by nitrous oxide and oxygen, with only an occasional whiff of ether. It is usually easy to deepen the anæsthesia if while this is being done the surgeon will stop working and have the

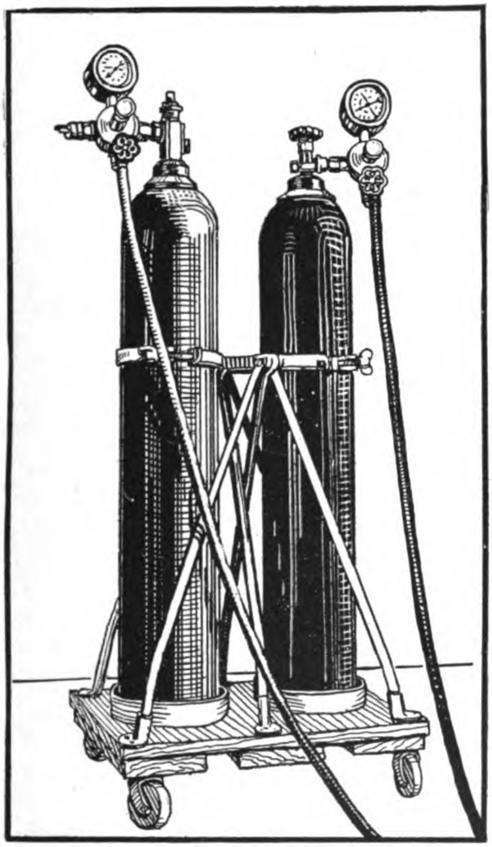


FIG. 4b. LARGE CYLINDERS OF NITROUS OXIDE-OXYGEN WITH DUPLEX GAUGES AND CONNECTING TUBES.

retractors released. After the major part of the operation is over, the patient is brought to a lighter anæsthesia; and after the peritoneum has been closed the operation is usually continued on an analgesic mixture.

Stertor or nausea during an operation usually means an overdosage of nitrous oxide; the remedy is increased oxygen. Nitrous oxide does not produce irritation of the throat; when this occurs it is usually due to the introduction of ether vapor too early in the anæsthesia. The occurrence of retching as the result of intra-abdominal manipulation usually indicates a need for deepening the anæsthesia.

In cases of intestinal obstruction absolute relaxation is usually needed, so that ether vapor is often necessary. The use of oxygen is a great factor in preventing shock in these operations. While the intestinal anastomosis is being performed, the anæsthesia is lightened, but is deepened again for the closing of the wound.

The occurrence of vomiting, which often comes on almost imperceptibly, is carefully watched for, and the mask instantly released by quickly taking off a hemostat. If there is vomiting from the beginning of the anæsthesia, the mask is held over the face, not attached with the towel. Sponges on a sponge holder are at hand to mop out the throat if necessary. The pulse is closely watched, and the patient kept warm.

In gastro-enterostomy, particularly on starved and anæmic patients, the use of ether is avoided, unless it is needed to secure relaxation during the exploratory part of the operation. During the anastomosis the amount of the anæsthetic can be reduced to the amount needed to maintain light anæsthesia or analgesia. The anæsthesia is deepened while the peritoneum is sutured and then lightened again to analgesia. Oxygen is an important factor in maintaining the safety of the patient.

With gall-bladder cases, particularly of the fat plethoric type, it is difficult to maintain an even anæsthesia, since the nature of the operation tends to produce arrhythmic respiration and prevent the even intake of the anæsthetic. The patient is put well asleep with nitrous oxide and oxygen. Ether is given if needed to secure relaxation, and then withdrawn. During the exploration, especially when contact is made near the diaphragm, extra whiffs of oxygen are given to maintain comfortable respiration. The exhaling valve is always released if there is any stress on the expiration.

When the patient is considered a poor risk, it is best to avoid the use of ether vapor, and to rely on local anæsthesia for the relaxation of the abdominal muscles. By maintaining a free air-way, and by the judicious use of oxygen the anæsthetist secures a comfortable respiration, which helps to relax the patient. Ether, if necessary, is given in whiffs to stimulate the respiration or to deepen the anæsthesia.

Septic cases, cases of acute appendicitis and peritonitis do better if the use of ether can be avoided. A slight duskiness, provided the respiration is unobstructed, is to be preferred to the use of ether.

In operations on the kidney the use of ether vapor is avoided by lengthening the period of induction and by increasing the nitrous oxide content of the anæsthetic mixture. The maintenance of a good respiratory exchange is of the utmost importance, and unless the respiration is free and unobstructed, a breathing tube is used. The patient should be well anæsthetized before he is moved to the position required by the operation (Fig. 5). Cyanosis is avoided. If ether is necessary it is always given in whiffs, not by adding a definite percentage of ether.

For genito-urinary operations nitrous oxide-oxygen, combined with local anæsthesia, is ideal. If ether vapor is required to secure relaxation or to deepen the anæsthesia, it is given early in the administration and

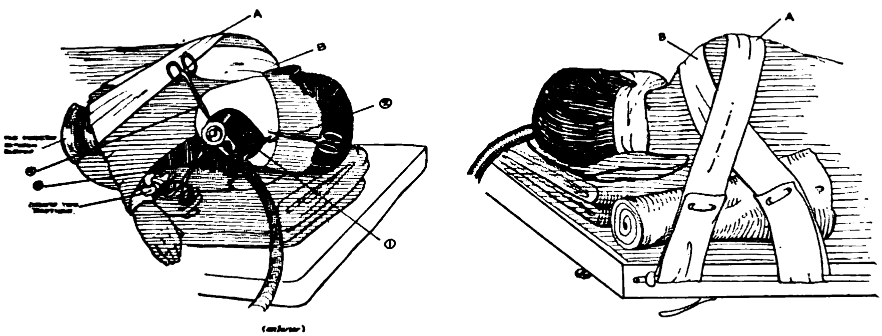


FIG. 5. POSITION OF PATIENT FOR KIDNEY OPERATION.

is discontinued as quickly as possible. If needed during any phase of the operation it is given in whiffs only.

In rectal cases special care is taken to keep the patient well oxygenated, particularly during the stretching of the sphincter muscle. If a local anæsthetic is used, the anæsthesia is usually uneventful and nitrous oxide and oxygen will hold the patient without the addition of ether. If a local anæsthetic is not used, ether may be necessary.

Operations on the extremities. For reducing dislocations the necessity for muscular relaxation requires the addition of ether to the nitrous oxide and oxygen mixture. The reduction of fractures, however, may be satisfactorily made under nitrous oxide and oxygen alone. For amputations, if low spinal anæsthesia, or local or regional anæsthesia is used, light nitrous oxide and oxygen do admirably.

Operations on the spinal cord. For these cases the ordinary technique applies, particular attention being given to assure that the patient is well asleep before he is placed in the prone position. These patients should be closely watched for signs of shock.

Operations for pleurisy, empyema, abscess of lung. In these cases the routine method of anæsthesia is used and the induction made as comfortable as possible. If cyanosis and dyspnœa are present, the patient is started on oxygen, and nitrous oxide is gradually added. The use of oxygen under positive pressure has proved helpful, and the patients seem more comfortable when this procedure is used.

The position of the patient on the table is important. A modified kidney position with no weight on the chest or shoulders secures maximum comfort. The use of ether vapor should be avoided. After the operation is over, oxygen should be given until the patient's respiration has become regular and of normal rate.

Operations around the head, face, and neck. For these cases nasal tubes are employed to eliminate the face mask from the field of operation. The anæsthetist should have graduated sizes of nasal tubes to fit any patient from infant to adult age (Fig. 6a).

The patient is anæsthetized in the usual way, except that 2 per cent of ether vapor is introduced after unconsciousness is secured to prepare the patient for the temporary administration of ether while the nasal tubes are being inserted. After anæsthesia is secured the mask is applied and drop ether used while the nasal tubes, which are attached to the nitrous oxide-oxygen machine, are inserted through the nose to the base of the tongue. The mouth is kept covered with gauze, and ether continued until the respiratory exchange in the breathing bag shows that the tubes are properly in place. The tongue is then pulled gently forward and held in place by a mouth sponge. In operations on the neck the mouth is covered with a moist towel to minimize the escape of nitrous oxide through the mouth. The tubes can be so adjusted that the surgeon may work with comfort on any part of the face or neck without interference from the anæsthetist. It is most important, however, for the anæsthetist to see that the tubes are not kinked or pressed upon and that the respiratory exchange in the bag goes on uninterruptedly. The goiter mask is always used to screen the anæsthetist from the operative field. After the tubes are properly placed, and the mouth packed, it is usually possible to continue with nitrous oxide and oxygen alone without the addition of ether vapor. There is practically no danger of obstruction unless blood gets into the throat.

For plastic operations on the nose the anæsthetic is administered in the usual way. An air-way is inserted and the nasal tubes put down to the pharynx through the mouth. The tubes are packed in place by mouth sponges, and the mouth is covered securely to prevent the escape of the gases.

In the removal of glands of the neck the face mask is adjusted in the usual way unless it interferes with the field of operation. When necessary, the nasal tubes may be inserted, and the anæsthetist may take the position most convenient for the surgeon, being screened from the field of operation by a goiter mask.

For operations upon the eye, the surgeons in the Lakeside clinic prefer nasal tubes which are adjusted according to the technique given

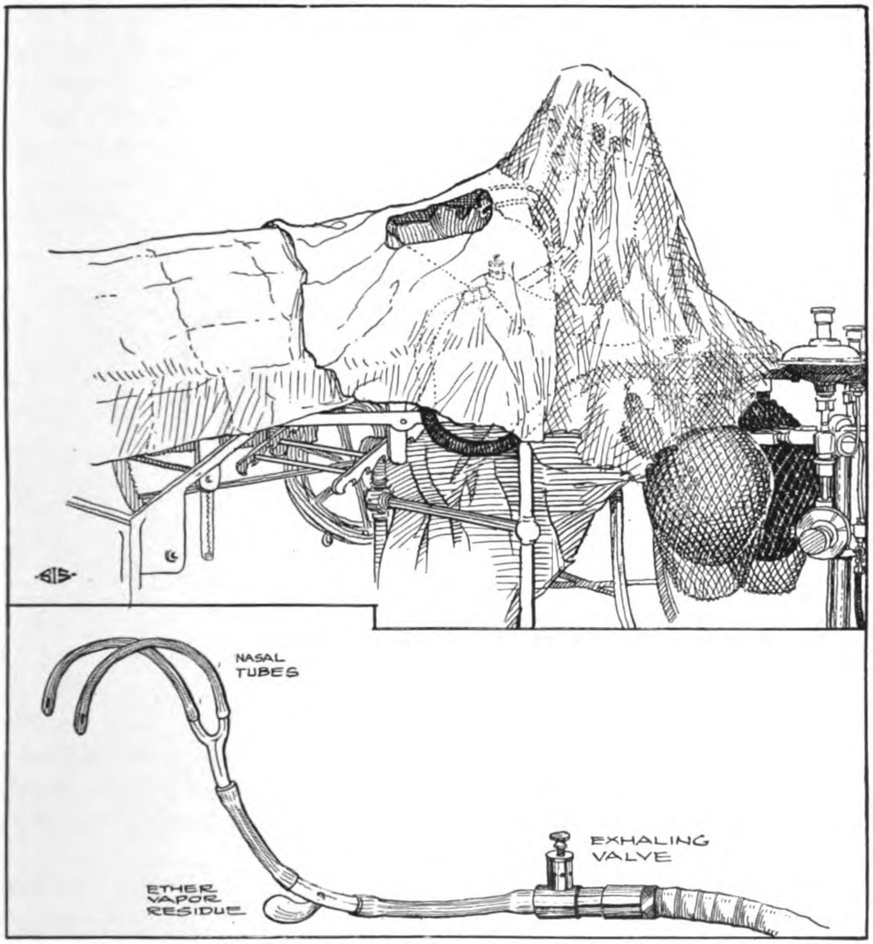


FIG. 6a. ADJUSTMENT OF NASAL TUBES FOR OPERATION ON THE FACE.

above. The anæsthetist is screened from the field by the mastoid screen, described in another section. The tubes are always adjusted so that the surgeon is not inconvenienced by the anæsthetist.

A laryngectomy at the Lakeside clinic is performed in two stages. For the first operation, the anæsthetic is given in the usual way. The fact that when necessary it is possible to give oxygen under pressure and so to overcome obstruction or distressed respiration adds greatly to the sense of security on the part of the anæsthetist, and to the safety of the patient. At the end of the first operation, the tracheotomy tube is usually inserted. The patient is then sent back to his room, and in the interval before the major operation becomes accustomed to breathing through this tube. The major operation is the laryngectomy performed several days later. For this the patient is anæsthetized through the trachea by means of a rubber tube to which an exhaling valve is attached (Fig. 7). This tube, which is sterilized, is held gently over the tracheal

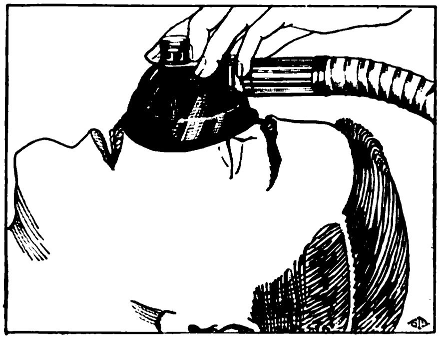


FIG. 6b. ANÆSTHETIC INHALER FOR THE EXTRACTION OF TEETH.

opening until analgesia is established. Then it is fitted closely over the trachea, and when anæsthesia has been secured it is slipped into the tracheal opening by the surgeon, and sutured into place. The anæsthetist changes to a position away from the field, and the goiter screen is adjusted. As the anæsthetist is entirely away from the field the second surgical assistant is charged with keeping the tracheal tube from being kinked or compressed.

The anæsthetic is given as usual; the nitrous oxide dosage, however, is even more closely watched than in other operations, as on account of the direct unobstructed feeding of the nitrous oxide and oxygen to the patient, the possibility of oversaturation must be constantly kept in mind. If for any reason oxygen is needed, it is readily given by switching over to the oxygen valve for a few breaths. The anæsthesia in these cases is usually uneventful. Since postoperative pneumonia is a special danger, it is important to avoid ether. After the operation the patient is given oxygen until the respiration is normal; then the tracheotomy tube is reinserted, and the patient is sent back to his room. The final plastic work is usually done under light analgesia, administered by holding the sterilized tube over the tracheotomy opening.

In mastoid operations the face inhaler is adjusted in the usual way except that the towel is applied lower down, and, where it would interfere with the field, a two-inch bandage is slipped through and the towel narrowed by tying the bandage tightly together. The side packing is then put in snugly to avoid leaking, and the head placed in the proper position. A small pad is put under the side of the face to tilt the head up and to help the anæsthetist keep the mask from being pushed out of place.

The maintenance of anæsthesia for a mastoid operation is usually a very easy procedure, the only point of special importance being to avoid

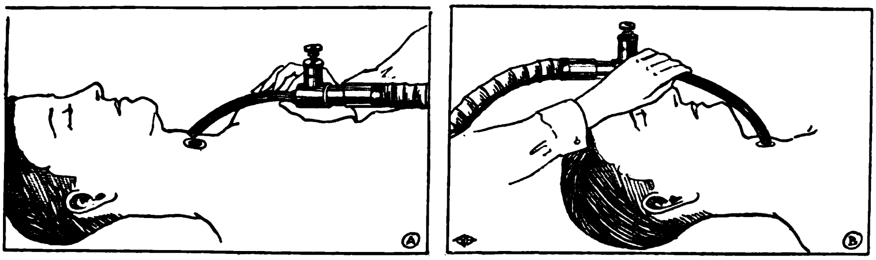


FIG. 7. TRACHEAL TUBE USED IN LARYNGECTOMY.

pressure, as this will increase the bleeding. The anæsthetist works with the exhaling valve open and if necessary secures tranquil respiration with an air-way. Cyanosis is avoided, and if the operator complains of increased bleeding in the field, the anæsthetist switches to ether and oxygen until this venous congestion is lessened.

In the Lakeside clinic the operators work with a head light and in a darkened room, and for this reason it is necessary for the anæsthetist to have a screened electric light which can be switched on and off when needed (Fig. 8).

For operations on the brain the same technique as for mastoid work is employed. It is of prime importance to secure a soft, even respiration and to avoid the use of pressure on the exhaling valve. In cases where the face mask would interfere with the field, nasal tubes are inserted. Usually light anæsthesia can be maintained. If ether vapor is required it is given early in the administration and then withdrawn if possible.

In adenoid and tonsil operations when drop ether is used temporarily, cold cream is applied to the patient's face, and extra precautions taken to protect the eyes. To children from one to ten years old, nitrous oxide and oxygen are given for induction. Ether vapor is then introduced slowly and increased until the patient is well asleep. Drop ether is used while the mouth gag is put in and the mouth tube adjusted. The anæsthetic mixture of nitrous oxide and oxygen plus ether vapor is then given through the mouth tube. Gauze is placed around the gag in such a way as to exclude air from the nostrils, and is so arranged that the loose ends can be brought up and folded over the mouth to prevent the escape of the anæsthetic through this orifice, while the surgeon controls bleeding by pressure. The anæsthetic can be augmented also by dropping ether on this gauze if such a procedure is necessary. On account of the open mouth it is usually necessary to force the ether vapor and to increase the pressure of the gases. This is done by screwing down part way the regulating valve at the top of the automat (Ohio monovalve). For tonsil operations on adults the Connell ether vaporizer with suction attachment is very satisfactory.

In the Lakeside clinic the nasal inhaler (Fig. 6b) is not often used, except for the administration of an anæsthetic for the extraction of teeth, or for establishing analgesia for minor work on the face when the nasal mask is feasible. In such cases the inhaler is placed over the nose, care being taken not to press up on the alæ and so close the nostrils. The patient is instructed to breathe through the nose and to keep the mouth closed. If the patient cannot do this, the mouth must be covered with a piece of rubber. For the extraction of teeth the patient should be well anæsthetized.

For cleft palate operations in children up to five years of age nitrous oxide and oxygen and ether vapor are given. Drop ether is used only for a few minutes while the mouth gag is being put into position, and the mouth hook and gauze adjusted, as for tonsil operations. The pressure on the oxygen automat is regulated so as to secure the necessary force to express the ether vapor, as with the wide open mouth the gas must be used under some pressure.

With little children 45 gallons per hour of nitrous oxide plus 5 – 15 per cent ether vapor, with enough oxygen to maintain an absolute pink color, is the usual mixture. Gauze is arranged around the mask in the same way as for a tonsil operation. The tongue is gently brought forward and held in position by a small silk suture through it. A small sponge is placed in the throat to prevent the inhalation of blood. The anæsthetist must remember that the sponge may slip too far down the pharynx and cause obstruction.

The special anæsthetic mouth tube must be kept out of the operative field, and the anæsthesia should be deep enough to prevent moving or any return of the throat reflex. It is annoying to the surgeon to have intermittent anæsthesia for such work, and it requires attention and skill on the part of the anæsthetist to maintain a smooth anæsthesia with the wide open mouth. It is essential that the child be well asleep before the operation is started. After the operation is over the child is turned on the side with the head slightly lowered, and is carefully watched for signs of obstruction from the collection of blood in the throat. It is most important to keep these children warm and out of drafts.

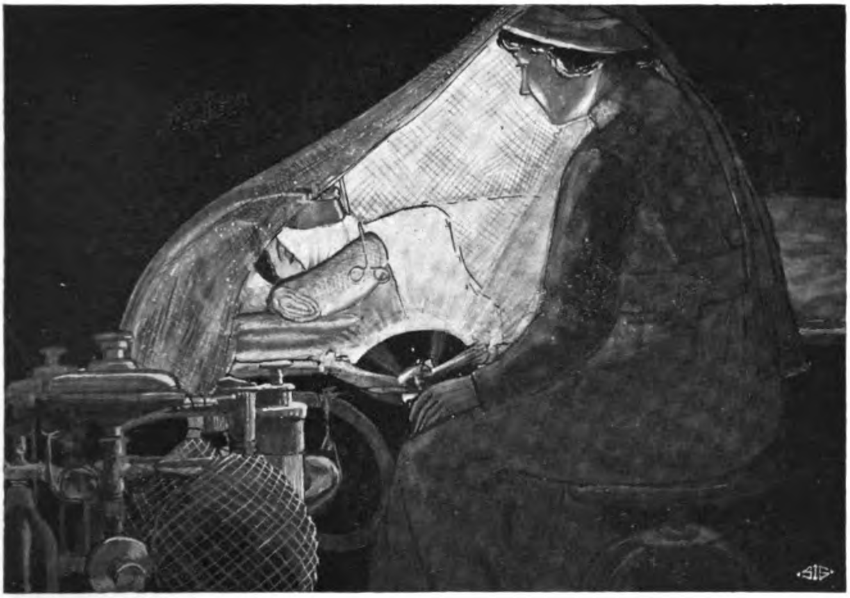


FIG. 8. ARRANGEMENT OF PATIENT FOR MASTOID OPERATION WITH SCREENED LIGHT.

For cleft palate operations in adults the Connell ether vaporizer with its suction attachment is used, but there should always be at hand the mouth tube attached to the nitrous oxide machine, so that oxygen can be given if necessary.

Operations for exophthalmic and obstructive goiter. Ligation of the superior thyroid artery is usually done in the patient's room under analgesia. The patient as a rule is given inhalations of nitrous oxide for several days before the actual ligation is to take place. The first inhalation is brief; the anæsthetist explains to the patient what is being done and notes the manner in which he takes the nitrous oxide, particularly with reference to any nervous reaction or change in the rate and character of the pulse. It is wiser not to try to give an inhalation with the patient propped up on several pillows. When the ligation is to be done a small firm pad is placed under the nape of the neck in such a manner as to extend the head and give the surgeon a better working field. If the patient protests that he cannot breathe without having his head raised, the pillows are allowed to remain, and are not removed until the patient is well under analgesia. By reason of the hyperactivity of respiration, the exaggerated sense of fear, the marked response to all stimuli, and the impaired heart function, it is a real achievement to keep a bad exophthalmic case under analgesia for a ligation or a thyroidectomy.

The only possible danger in operating under analgesia is shock from pain, for it must be remembered that analgesia does not always secure indifference to an unexpected or sudden injury. If such an injury is not quickly covered with sufficient anæsthesia to take care of the reflex, the patient may become excited and hard to manage. Another serious difficulty is the endeavor of the patient to escape hurt by moving, and by trying to get his hands in the field of operation. With the use of a local anæsthetic in combination with the nitrous oxide, this difficulty is almost obviated. If for any reason the patient cannot be comfortably controlled with analgesia, the wisest course is to secure a quiet patient by means of deeper anæsthesia, and after the hard part of the operation is over to return to analgesia.

After analgesia is well established, the hands are pinned to the draw sheet for the ligation. The surgeon then comes in and the patient is prepared for operation. After the ligation is finished, the surgical staff go out of the room, the instruments and linen are removed, the room darkened, an ice cold cloth placed over the patient's eyes, ice bags applied to his heart, and he is allowed to waken to exactly the same environment as that in which he went to sleep.

Following the second ligation, after a period of rest under the direction of the surgeon, the patient is again given inhalations preliminary to the thyroidectomy. On the day on which the operation is to be performed, the procedure is the same as before ligation, except that the patient is completely anæsthetized. When anæsthesia is established he is taken to the operating room. During the operation, as light an anæsthesia as possible is maintained. Cyanosis is never permitted under any circumstances. Ether is always avoided if possible.

After the operation is over the patient is brought to a state of analgesia, and the dressing put on. He is then lifted from the operating table to the wheel stretcher, and the breathing tube is switched back to the portable machine. The patient is conveyed back to the ward under analgesia. Ice bags are applied to the heart and ice cold cloths to the head. As after the ligation, the patient awakens in a cool, darkened room with only the anæsthetist and the nurse present.

If there is any distress in respiration, oxygen is given until the patient is comfortable. In severe cases a wheel bed with pillows arranged comfortably is taken to the operating room, and the patient is lifted from the operating table directly to the bed.

Exophthalmic goiter patients present a special problem to the anæsthetist, for they need the most careful attention and their condition must be accurately gauged. It is essential to remember that the exaggerated need of oxygen by these patients must be supplied.

If there is encroachment or pressure on the trachea oxygen under pressure is the remedy. Obstruction to respiration must not be tolerated. Even a slight obstruction which would pass with only slight disturbance to a more stable patient, is a source of fatigue and possible shock to these highly sensitized patients. A failure to respond to oxygen when the mechanism of breathing is properly taken care of is a matter of grave anxiety, and must be reported promptly to the surgeon, for in rare instances it may be necessary to resort to tracheotomy.

Any surgical procedure involving injury or pressure on the laryngeal nerve produces marked stertor and disturbances of the respiration. Oxygen given under pressure, and lighter anæsthesia, if possible, are the best procedures. Unfortunately this involvement brings with it the restlessness which interference with the process of breathing may produce. To cover this complication anæsthesia must sometimes be deepened. It is here that the ability of the anæsthetist is taxed, for the problem of maintaining a quiet patient, and at the same time taking care of the exaggerated need of oxygen, is a hard one. The pressure sense is much exaggerated in these patients, and it is therefore necessary to cover with deeper anæsthesia the procedure of dislocating a deep goiter.

Obstetrical operations. Our experience with obstetric cases has been limited. Analgesia during the labor pains, increasing to anæsthesia for the delivery of the head, and then returning to analgesia, has proved a satisfactory technique. The hyperactivity of the respiration of these patients necessitates an increase in the volume of the gases. A deep anæsthesia is contra-indicated, and the oxygen content should be carefully watched for the sake of both the mother and the child.

TECHNIQUE FOR SPECIAL TYPES OF CASES

It is essential that the technique of administration to children should be very conservative and elastic. The administration of the anæsthetic is started slowly, the mask being held away from the child's face, and the gas allowed to flow over the face until sleepiness is induced. The dosage is diminished if signs of cyanosis appear. As the induction progresses, the mask is brought down, but is not fitted closely as in an adult. It is held so that the child can breathe into it with a fair amount of comfort. The exhaling valve is left wide open. The shallow respiration of children usually makes it necessary to consider the danger that carbon dioxide may accumulate in the breathing tube. To obviate this

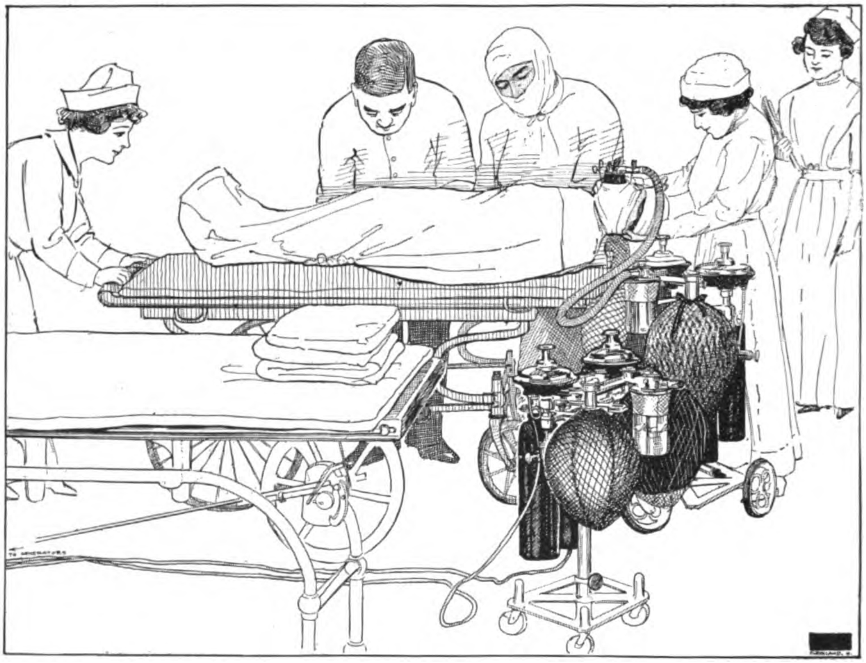


Fig. 9. TRANSFER OF ANÆSTHETIZED PATIENT FROM WHEEL STRETCHER TO THE OPERATING TABLE.

the nitrous oxide content is kept as fresh as possible. A very low nitrous oxide content is used, and until respiration is established 2 – 5 per cent of ether vapor is added to the mixture. If mucus accumulates, we may discontinue the ether vapor and cautiously increase the nitrous oxide to a point not exceeding 60 – 70 gallons per hour, with enough oxygen to maintain a perfect color. If obstruction occurs we slip in a small air-way and try to avoid ether temporarily. After the saturation point is reached, the problem is much simpler, and the child usually goes on very well on a nitrous oxide content of 45 gallons per hour with sufficient oxygen to secure good color, and 3 – 5 per cent ether vapor. No definite rule as to the amount of oxygen can be given; the anæsthetist must follow the clinical guides of a good color and a comfortable respiration.

If for any reason the operation is prolonged, special caution must be exercised to avoid the possibility of an overdosage of gas, the sign of which will be paleness of the child's face. We are always concerned when anæsthesia in a small child is prolonged over 45 minutes. An hour is the maximum safe period. The rule that patients must be protected from drafts and kept warm should be particularly observed with little children.

With children over 5 years and under 10 years the same technique as with younger children is observed except that the subject is usually better adapted for anæsthesia; he breathes through the face inhaler and tube with more comfort; and it is safer to increase the nitrous oxide dosage. However, the instability of children under anæsthesia should be always borne in mind, and the anæsthetist should make a special effort to maintain an even anæsthesia.

Anæmic and frail children must be watched closely. With such children the anæsthesia is started with oxygen; the nitrous oxide content should be added as cautiously and quickly as the condition warrants. Anæmic children require a longer induction period and must be carefully watched to avoid oversaturation with the anæsthetic. The possibility of status lymphaticus should be borne constantly in mind. Fat children with pasty complexions also require special care.

The young adult is usually a safe subject for anæsthesia, but for a short time in the second stage may be a little troublesome. The nitrous oxide and oxygen produce unconsciousness so quickly that trouble comes mostly in the second stage. Usually the respiration is overactive, and the danger of overdosage must therefore be kept constantly in mind. Nausea, too, seems to occur more frequently during this period.

If nitrous oxide does not give complete anæsthesia, ether vapor is added, but on account of mucus and vomiting it is well to work off the ether content as quickly as possible. A tendency to spasm and to clinching of the teeth is often noted in this type of patient, particularly in young boys, and it is therefore important to make sure that the gauze dental plug is inserted between the teeth before the administration of the anæsthetic is started.

Young adults are not good subjects for analgesia, and therefore it is easiest to secure complete unconsciousness first, and then bring the patient back slowly to the analgesia stage.

Adults above 21 years of age when in normal condition take nitrous oxide and oxygen safely, although the individual physical characteristics modify or increase the anæsthetic problem. These patients usually have good mental self-control, which adds to the safety of the anæsthesia.

Elderly people as a rule take anæsthetics well. Special care must be taken in cases of arteriosclerosis and chronic bronchitis to avoid cyanosis. In most cases after anæsthesia is established a lighter mixture of the gases is possible, from 60 to 90 gallons of nitrous oxide per hour, with oxygen sufficient to maintain an easy respiration and good color. If necessary, ether is given in whiffs early in the anæsthesia. These patients are usually good subjects for analgesia.

Athletes and alcoholics are alike in being a cause of anxiety to the anæsthetist. With such cases it is better to use nitrous oxide and oxygen alone in the induction stage. The mask is adjusted under very light analgesia so that the mental control of the patient by the anæsthetist may not be lost. The second stage is made as short as possible, particular heed being paid to the oxygen content of the anæsthetic mixture. If there is muscular activity more oxygen is required. Pressure on the exhaling valve is avoided until the patient is unconscious. As in most cases, ether must be added to secure necessary relaxation; about 2 per cent is cautiously introduced to anæsthetize the mucous membrane. When the active second stage appears, the percentage of ether can be quickly increased to a dosage that will control the patient. With alcoholics a good color is usually maintained with from 115 to 130 gallons of nitrous oxide per hour, with sufficient oxygen to maintain color, and from 15 to 18 per cent of ether. This mixture is continued until the respiration becomes regular and quiet, and the patient is well asleep and relaxed. The ether content is then diminished cautiously, and if possible is discontinued altogether. If during the operation it appears that the nitrous oxide content cannot safely be increased, whiffs of ether, 15 per cent, may be given as indicated by the state of the patient. It is essential to avoid cyanosis. To obviate the danger of bronchitis or pneumonia, it is of prime importance to give the least possible amount of ether required to secure the necessary relaxation and depth of anæsthesia, and to make sure that the patient is properly protected from drafts.

It usually requires a longer time to anæsthetize obese than normal patients. Ether should be avoided until the patient is completely unconscious; then, if necessary, ether is added to the nitrous oxide-oxygen mixture. If the operation is abdominal and more relaxation is called for, a small percentage of ether is needed until the patient's mucous membrane is anæsthetized, after which sufficient ether is added to secure the relaxation demanded by the surgeon.

The possibility of obstructed breathing is always present in these cases, and if it occurs even to a slight degree an air-way should be inserted at once and the mask re-adjusted. If the Trendelenburg position is required, extra oxygen is given while the adjustment is being made. Fat patients do not tolerate the Trendelenburg position for any length of time. Ether is badly borne by fat people; if its use is necessary, it should be given early in the anæsthesia, and discontinued as soon as possible.

In the presence of pulmonary tuberculosis every effort should be made to avoid the use of ether.

The quick unconsciousness induced by nitrous oxide and oxygen helps to control insane patients. It is important to have assistants at hand to hold the patient if necessary, so as to get him to sleep as quickly as it can be safely accomplished.

Epileptics must be watched closely for the onset of an attack. The mouth prop should always be inserted before starting the anæsthetic. If a seizure should occur, the anæsthetic dosage must be decreased immediately. In one case in our experience, when an attack occurred during an abdominal operation, oxygen relieved the spasm; and decreasing the gas mixture to an analgesic dosage controlled the patient for the remainder of the operative procedure. A wooden mouth gag should be inserted during the period of recovery from the anæsthetic, to avoid the possibility of the patient's biting his tongue.

Cachectic patients and poor risks are usually in a state of acidosis and must be carefully watched during the induction stage. These patients demand more oxygen than do normal patients, and the lightest possible anæsthesia compatible with the operative procedures should be maintained. They should be watched closely for symptoms of shock and must be kept warm. The duration of the anæsthesia is a matter of concern, and therefore when an operation is prolonged the anæsthetist must be careful to diminish the dosage as quickly as is consistent with the maintenance of unconsciousness. Combined local and general anæsthesia is especially important in these cases.

Patients with heart disease usually take nitrous oxide and oxygen quite comfortably. It is of special importance to give them a slow and easy induction, avoiding any struggling or resistance, and to maintain a good color and unobstructed respiration. The anæsthesia should be deep enough to keep the patient quiet. The nitrous oxide content is increased cautiously and whiffs of ether vapor, 10 – 15 per cent. are given, unless a quiet and even respiration with good color can be maintained by the gas mixture alone. In placing these patients in the Trendelenburg position, color and pulse are carefully watched throughout the operation.

Usually 80 or 90 gallons of nitrous oxide per hour with sufficient oxygen to maintain color, and with whiffs of ether when necessary, will prove a satisfactory mixture for these cases. In the Lakeside clinic these patients are given special pre-operative care and rest, an important factor in minimizing anæsthetic complications.

Our confidence in the value of nitrous oxide-oxygen as compared with ether is based upon an experience which includes 32,100 administrations by the anæsthetic staff of Lakeside Hospital. In this series there has been but one anæsthetic death, and this due to the unfortunate fact that a difficult case was entrusted to an anæsthetist who had not yet completed her training.

While nitrous oxide is far more expensive than ether, and imperatively demands a specially trained anæsthetist for its safe administration, the comfort and, above all, the safety of the patient make it an eminently satisfactory and useful anæsthetic.

CHAPTER III

LOCAL ANÆSTHESIA

THE attempt to produce local anæsthesia so as to render operations painless is not new, but dates back many centuries. All of the older methods, however, have now but an historical interest. Many of them, such as the local use of lizard oil, powdered crocodile skin, prolonged pressure, constrictors applied about an extremity partially to interrupt the circulation, the spraying of carbonic acid gas on a raw or denuded surface, freezing by the use of snow or ice, undoubtedly had some effect in benumbing the parts, but all of these, with the exception of freezing, have long since fallen into disuse. Freezing still finds a very limited use when it is desired to make short and superficial incisions for the opening of abscesses, or to render the skin anæsthetic before introducing a trocar or exploring needle. Anæsthesia produced in this manner is of very brief duration.

The best method of freezing a small area is by the use of the ethyl chloride spray. Ethyl chloride is a colorless, volatile, inflammable liquid with a boiling point between 12 and 13 degrees centigrade. It is furnished the trade in glass tubes containing from 30 to 60 ccm., with a fine capillary delivery tube having an automatic closing cap. When the cap is opened and the glass tube held in the hand, with the cap end down, a fine stream of ethyl chloride is projected from the capillary tube. This should be sprayed on the part to be frozen until the skin becomes white and feels hard and leathery; it is then ready to be incised. Care should be taken not to freeze the part too deeply or to continue the freezing too long, as the tissues may be injured so that necrosis results.

The marked degree of vasoconstriction which is produced by the intense cold is followed by vasodilatation when reaction comes on, and a local hyperæmia may persist for some time. Reaction is also usually accompanied by more or less pain of a burning character. When it is desired to limit the effects of ethyl chloride to a small area the surrounding parts may be protected by smearing them with vaseline.

Freezing about the eyes and anus, if done at all, should be carried out with great caution.

Modern local anæsthesia dates from the discovery of the local anæsthetic properties of cocaine. While Scherzer probably was the first to report on the anæsthetic properties of cocaine, it was not until Koller in 1884 demonstrated that the instillation of a two per cent solution of cocaine in the eye produced a sufficient degree of local anæsthesia to permit the performance of operations upon the eye without pain that the substance came into general use. At first the high cost of the natural alkaloid made from the cocoa plant (erythroxolon cocoa) materially restricted its use, but the discovery of synthetic cocaine soon placed the substance within the reach of all. Ophthalmologists were the first to make extensive use of cocaine anæsthesia, but the fact that a solution of cocaine produced anæsthesia when applied to any mucous membrane soon led to its use by laryngologists and rhinologists, and later by all surgeons in operations on exposed mucous membranes. Cocaine was a great boon to eye, ear, nose, and throat surgeons, and its use greatly advanced nasal and laryngeal surgery by permitting operations to be performed on the nose and throat which hitherto had been quite impossible.

A solution of cocaine produces no effects when applied to the unbroken skin; it is reasonable to assume, however, that an agent so potent when applied to mucous membrane must also be effective if brought in contact with raw or denuded surfaces, or if injected into the tissues beneath the skin; and experience has demonstrated that such is the case. Careful experimental investigation of the physiological action of cocaine shows that it has the effect of inhibiting or arresting temporarily or permanently the activity of all living protoplasm. It produces anæsthesia, therefore, by arresting temporarily the activity of the sensory nerves with which it comes in contact. It either has a special or elective affinity for nerve cells, or the activity of nerve cells is more easily affected than that of other living cells. Affecting as it does the activity of all nerve cells, it is immaterial whether it be brought in contact with the nerve endings, with the nerve in continuity, or with the nerve centers, so far as the production of anæsthesia is concerned.

If the nerve with which it comes in contact be a motor nerve, paralysis of motion takes place; if the nerve be both sensory and motor, sensation is lost before motion.

The term local anæsthesia applies to all forms of anæsthesia, however induced, which affect a more or less limited area of the body in a conscious person. When the anæsthesia is produced by applying the substance to the peripheral nerve endings it is called peripheral or infiltration anæsthesia. When the substance is applied to a limited portion of a nerve trunk in continuity it is called regional or conduction anæsthesia, or nerve blocking; when it is injected into the central spinal canal it is called central or spinal anæsthesia. Spinal anæsthesia is discussed in the following chapter.

The great toxicity of cocaine was not sufficiently recognized at first and many deaths resulted from its use, both locally on mucous membranes and after subcutaneous injections. Many of these deaths occurred suddenly, and some of them after small doses. Such unfortunate accidents naturally greatly restricted the use of cocaine and for a time materially retarded the development of local anæsthesia. Its advantages and possibilities, however, had been recognized, and efforts to find a substance which would suspend sensation when injected subcutaneously, and at the same time be free from the highly toxic properties of cocaine, received a new stimulus. As a result, a great many synthetic products were discovered which possess anæsthetic properties in greater or less degree. Among these may be mentioned alypin, anæsthesin, apothesine, benzyl alcohol, chlorbutanol (chloretone), cycloform, eucaine-a, eucaine-b, holocaine, nirvanin, novocaine (procaine), orthoform, quinine urea hydrochloride, stovaine, and tropacocaine. All of these substances possess anæsthetic properties in varying degree, but not all of them have proved to be of practical value. There are certain properties which a substance should have in order to be of practical value in local anæsthesia work. These are: (1) anæsthetic properties; (2) solubility in water; (3) relative non-toxicity; (4) ease of sterilization; (5) freedom from irritating qualities. Of these cocaine lacks the third and fourth. It is perhaps the most powerful local anæsthetic known, and likewise the most toxic; for that reason it is used as the basis of comparison in expressing the anæsthetic properties and toxicity of other substances.

Some of the above mentioned substances, namely, cycloform, orthoform, and anæsthesin, are so insoluble in water that they may be eliminated from further consideration in this connection. Holocaine is slightly soluble, but irritating when injected subcutaneously, and highly toxic. It is therefore seldom used. Chlorbutanol (chloretone) is soluble in water in the ratio of 0.8 parts per thousand; its anæsthetic properties are too weak to permit it to be used alone, but when added to the extent of saturation to solutions of other substances it is of advantage in prolonging the anæsthesia, by reason of its adjuvant action. Nirvanin is a soluble form of orthoform. Its anæsthetic properties are quite weak, being only about one-tenth those of cocaine. As it is also slightly irritating when injected subcutaneously it has found very little use in suregry. Stovaine and alypin are similar chemically, and the latter is derived from the former. Both of them have quite marked anæsthetic properties, both are freely soluble in water, and when applied in solution to a nerve trunk interrupt its conductivity. A 4 per cent or 5 per cent solution of stovaine applied to a nerve trunk causes irreparable injury to the nerve, according to Läwen and Braun (*Local Anæsthesia*, 1914, p. 119). A 5 – 10 per cent solution of stovaine injected into the skin has caused sloughing which extended as far as the subcutaneous tissue. The use of weaker solutions, 0.1 – 1 per cent, causes pain at first, but does not permanently injure the tissue. The anæsthesia which soon results is quite complete and lasts from 8 or 10 to 25 minutes according to the strength of the solution used. Gangrene of the skin has been observed after the use of a 2 per cent solution. It is highly toxic and a number of deaths have occurred from its use. The injection of a solution of alypin is likewise painful, but the wheal produced becomes anæsthetic at once—the anæsthesia lasting from 10 to 20 minutes. Gangrene has not been observed after its use, but the injection of 50 ccm. of a 2 per cent solution caused death in a sixteen year old girl. It is evident from the above that stovaine and alypin are not suitable for general use as local anæsthetics.

Eucaine-a and eucaine-b are two somewhat similar synthetic alkaloids; the former is insoluble and so seldom used that it has been practically withdrawn from the market. The latter, or beta-eucaine as it is more commonly called, while rather insoluble as a base, is freely soluble as a hydrochloride or lactate salt. Its solution in water is quite stable and will withstand boiling. A 0.1 – 1 per cent solution injected subcutaneously produces local anæsthesia which is somewhat slower in its onset and less marked than that following the use of cocaine. It causes no irritation when injected in indifferent solutions. It is about one-third as toxic as cocaine, but the degree of toxicity depends somewhat on the concentration of the solution; for instance, L. C. Braun reports marked toxic symptoms lasting about 15 minutes following the injection of 1 ccm. of a 3 per cent solution into a nerve trunk in the forearm. This result, however, is unusual, as much larger quantities, for instance, 100 ccm.–300 ccm. of a 0.1 per cent solution, have been injected without toxic symptoms. While beta-eucaine is a substance of some merit, its use has materially decreased of late, owing to the discovery of more suitable substances. Tropacocaine is an alkaloid obtained first from cocoa leaves, but since produced synthetically. As a hydrochloride salt it is readily soluble in water and it can be sterilized by boiling. Its action is similar to that of cocaine, but less intense and much shorter in duration, for which reason it is seldom used today. It is quite toxic, and although no cases of death following its use seem to have been reported, it must be used with great caution.

Benzyl alcohol, one of the latest claimants for recognition, while of low toxicity, is so weak in its anæsthetic properties as to be of little practical value.

Although quinine in some form had been injected subcutaneously for many years, it was not until 1905 that Thibault first discovered the local anæsthetic properties of the soluble quinine salts. Quinine bisulphate and quinine and urea hydrochloride in solution, when injected subcutaneously, produce in a few minutes an area of complete anæsthesia. The degree and duration of the anæsthesia depend upon the amount injected and the strength of the solution. The anæsthesia appears much more slowly than that produced by cocaine, but it possesses the remarkable property of persisting much longer than that produced by any other known substance. Quinine and urea hydrochloride is the most soluble of the quinine salts in water, and for that reason is the one most commonly used for local anæsthetic purposes. The solution can be readily sterilized by boiling. The long duration of the anæsthesia produced, together with the fact that the substance is practically non-toxic, soon led to the belief that a safe, efficient local anæsthetic had at last been found. It was not long, however, before unfavorable results were noted. The injection of a solution stronger than 0.25 per cent produces a marked induration of the tissues, the degree of induration increasing with the strength of the solution. The swollen and indurated area may assume a mottled ecchymotic appearance, and necrosis, or sloughing of the tissues, may occur. Hertzler, who has made a careful study of the action of this solution, has shown that the induration is not due to a cellular infiltration, but to a true fibrinous exudate. It is this fibrinous exudate which, by obstructing the circulation in the capillaries, is mainly responsible for the sloughing when it occurs. The induration even though not sufficient to cause sloughing may delay the healing of the wound. When the strength of the solution does not exceed 0.25 per cent the amount of fibrinous exudate is quite small and harmless, but with solutions of 1 – 3 per cent the danger of sloughing becomes quite great. The prolonged anæsthesia which follows quinine injections is due to the deposit of fibrin which takes place. The anæsthesia may last from several hours to five or six days; such a duration is frequently a great advantage, as the patient is spared the usual postoperative pain and burning in the wound. It is particularly in operations about the anus and lower rectum that this prolonged anæsthesia is desirable, as the postoperative pain in these cases is often severe. It is questionable, however, whether the prolonged anæsthesia is sufficient compensation for the risk of delayed union and the possibility of an occasional slough. Notwithstanding the unfortunate accidents which occasionally have occurred from the use of quinine and urea hydrochloride, the drug is a useful one provided it be used with care and in proper locations. It is an advantage at times to add a small amount of the drug, for example, 0.1 – 0.2 per cent, to other local anæsthetics for the purpose of prolonging the anæsthesia.

The drug which has been used more extensively than any other in the production of local anæsthesia for surgical purposes is novocaine hydrochloride. This substance is now manufactured in this country under the name of procaine, which term we will use hereafter. Procaine possesses in a high degree the five essential properties of a good local anæsthetic, namely, (1) it is highly anæsthetic; (2) it is soluble in water; (3) it is relatively non-toxic; (4) it is readily sterilizable; (5) it is non-irritating when injected into the tissues. The anæsthetic properties of procaine are only slightly inferior to those of cocaine of the same strength, but as it is from 6 to 8 times less toxic than cocaine, and as it is readily sterilizable in solution, it has almost entirely displaced cocaine as a local anæsthetic for injection purposes; for local use in the eye and on certain mucous membranes cocaine in the majority of cases is the drug of choice, for the reason that it acts much more readily on these surfaces than procaine. Procaine may be used in 0.25 – 2.0 per cent solutions, depending upon the location of the injection and the particular purpose for which it is used.

Apothesine is a comparatively recent American discovery of great value. It possesses very strong anæsthetic properties, it is readily soluble in water, its solution can be sterilized by boiling, it has a relatively low toxic coefficient, and it is non-irritating to the tissues. With solutions of the same strength the onset of the anæsthesia is perhaps a little slower with apothesine than with procaine, but the anæsthesia is just as complete and the duration as long.

Toxicity. All known drugs which have the property of producing local anæsthesia are toxic. All of the above-mentioned local anæsthetics are protoplasmic poisons, with a greater or less affinity for nerve cells. It is self-evident that any substance which possesses the property of suspending the activity of nerve cells either temporarily or permanently must cause death if brought in contact with nerve centers or nerve fibers in sufficient strength.

The toxic action of cocaine has been referred to more extensively than that of other local anæsthetics for the reason that it is the most toxic of the drugs of this class. Many experiments have been made to determine the fatal dose of cocaine, but there are so many conditions which influence the results that a definite answer cannot be given. The rapidity with which toxic symptoms supervene, and their intensity, depend upon the method of introduction and the concentration of the solution used. When the drug is introduced directly into the circulation in sufficient amount, death may result almost instantly; when introduced subcutaneously, intramuscularly, or intraperitoneally, the symptoms depend upon the rapidity of absorption. Death is produced by the action of the drug on the nerve centers. The activity of these centers is suspended in the same way as the activity of the peripheral nerve endings or of the nerve fibers in continuity when the drug is brought in contact with them. The concentration of the solution is of great importance, for the injection of a small amount of a concentrated solution may produce more serious symptoms than the injection of several times the amount of the drug in a much weaker solution. The rapidity with which a solution is injected is also a material factor in determining the result. If a solution of cocaine, 1 : 200, be injected into the vein of a rabbit at the rate of 5 ccm. per minute, the rabbit will die when it has received 0.06 gm. per kilogram of weight. If the rate of injection be increased to 10 ccm. per minute, the rabbit will die when it has received 0.04 gm. per kilogram; but if the rate be decreased to 5 ccm. in ten minutes, the rabbit will be able to stand 0.09 gm. per kilogram before death takes place (Piquand and Dreyfus).

When it is injected subcutaneously a much larger quantity is required to cause death. Braun states that it requires five times as much cocaine in a 0.1 – 0.2 per cent solution injected subcutaneously to produce the same degree of toxicity as is produced by a 5 – 10 per cent solution. Likewise, toxic symptoms are much more frequently seen after the application of a small quantity of a strong solution to mucous membranes than after the use of much larger quantities of weaker solutions. These facts point to the same conclusion that the symptoms depend upon the quantity of the drug that reaches the central nervous system in a given time.

Man is much more susceptible to the action of cocaine than are the lower animals; therefore, conclusions drawn from animal experiments as to dosage are not applicable to man. Owing to the varying susceptibility of different individuals to cocaine, it is very difficult to state what the minimum dangerous dose of the drug is. Death in less than a minute is reported to have followed the subcutaneous injection of 12 drops of a 4 per cent solution in a girl of eleven years, and death has also followed a local application to the gums of 20 drops of a 5 per cent solution (Allen). While in most of the cases in which death occurred strong solutions were used, solutions of 1 per cent and even weaker may cause very alarming symptoms. The author has seen two cases in which the hypodermic injections of a very few drops of a weak solution caused alarming symptoms of collapse. In each of these cases less than 1/16 of a grain, 0.004 gm., of the drug had been injected. It is not uncommon for individuals to have an idiosyncrasy for cocaine, and this fact taken in connection with the further fact that it is highly toxic for all individuals, is sufficient to condemn the use of the drug for local anæsthesia in general surgical work, although it finds a field of usefulness in eye work and other specialties.

What has been said of the danger connected with the use of cocaine applies equally well to alypin, stovaine, and tropacocaine. These drugs may be readily dispensed with in general surgical work, since there are other much less toxic substances possessing great anæsthetic properties.

Procaine (novocaine) and apothesine are so superior to all other known local anæsthetics that they have practically superseded all of them in this field of work. While procaine and apothesine are only about one-eighth or one-tenth as toxic as cocaine and are therefore said to be relatively non-toxic, it should not be forgotten that death may be produced quickly by either of them if injected directly into the circulation.

Preparation of the solution. The preparation of the solution of procaine or apothesine is a simple matter, but one that requires punctilious attention to detail. Sterilization of the solution is essential, if one would guard against an occasional infection of the wound with sloughing. When sloughing has occurred it can usually be traced to failure to sterilize the solution properly. It is generally supposed that ordinary water is easily sterilized, but such is not always the case. Ordinary tap water frequently contains anaerobic spore-forming organisms, which are very difficult to kill, and the use of such water, even after boiling, has been followed by sloughing. Therefore, distilled water which has been thoroughly sterilized in an autoclave under pressure, or by fractional boiling, should be used.

Procaine and apothesine will withstand boiling in water a reasonable length of time, but prolonged boiling diminishes and eventually destroys their anæsthetic properties. The water, therefore, should be sterilized before the addition of the anæsthetic, and after the addition of the required amount of the drug the solution should be reboiled from three to five minutes. The solvent may be sterile distilled water or physiologic salt solution or Ringer's fluid. The injection of distilled water into the skin causes some pain, which persists until the water is absorbed or until it becomes of the same osmotic tension as the tissue fluids. When procaine or apothesine is added to the water, anæsthesia follows so quickly that the injection, unless the fluid be forced in too rapidly, is scarcely perceptible.

As all local anæsthetics are complex substances which are easily decomposed, nothing should be added to the solution which is incompatible with or which will break down the substance at high temperature. There are some things that can be added to the solution when it is cold that cannot be safely added before the solution is boiled. It is always advisable, therefore, to sterilize the substance alone, and if anything is to be added later, to add it after the solution has cooled. Even if two or more anæsthetics are to be combined for any purpose, it is better to sterilize each separately and mix them later as desired. After the solution has been sterilized it is allowed to stand about fifteen minutes until it has cooled to 160° F. The author then adds to the solution 1 per cent of chlorbutanol (chloretone). Chlorbutanol is soluble in water only to the extent of 8 parts per thousand. The addition of 1 per cent, therefore, simply insures a saturated solution, and the remaining few undissolved crystals settle at the bottom as a slight harmless deposit. The chlorbutanol should never be added before the solution is boiled, as it is decomposed at the boiling temperature, and the solution turns a lemon yellow color and becomes toxic. Chlorbutanol has slight anæsthetic properties of its own, and therefore intensifies the action of procaine and apothesine. It also has mild germicidal properties which are desirable if a solution is to be kept any length of time before using. It is always better, however, to use fresh solutions.

The anæsthesia following the injection of procaine or apothesine into or under the skin is of comparatively short duration, varying from five to twenty minutes, according to the strength of the solution used. Since this time is too short for the performance of anything but minor operations it is necessary to use some means of prolonging the anæsthesia. Epinephrin, by reason of its effect in contracting the arterioles and small capillaries, delays the absorption of the solution and greatly prolongs anæsthesia. It also permits the use of much weaker solutions. There are other substances that may be added to the solution which have the same effect. Hoffmann and Kochmann (*Deutsche med. Wchnschr.*, 1912, xlviii, 2264) believe that the addition of 0.25 per cent potassium sulphate increases the degree of anæsthesia so that a 0.25 per cent or even a 0.2 per cent solution of procaine will produce anæsthesia equalling that of a 0.5 per cent solution without the potassium sulphate. Potassium salts alone have some anæsthetic properties, but when combined with procaine, the anæsthesia produced is greater than the sum of both used alone.

The author has found that calcium chloride added to the solution also greatly prolongs the anæsthesia, undoubtedly because of delayed absorption of the fluid. From 0.25 per cent to 1 per cent may be added, the amount depending upon the length of time it is desired the anæsthesia should last. The addition of both calcium chloride and potassium sulphate still further prolongs the anæsthesia so that it may be extended to three or four hours. The calcium chloride and the potassium sulphate solutions should be prepared separately, so that the amount to be added may be varied to meet the needs of the particular case. For ordinary work the author has prepared a 1 per cent solution of procaine or apothesine and a 2 per cent solution of calcium chloride and of potassium sulphate. Three parts of the anæsthetic solution with one part each of the calcium chloride and the potassium sulphate solutions, with the addition of 3 – 5 drops of a 1 : 1000 epinephrin solution, will produce a complete anæsthesia, which will last two hours or more. By increasing the calcium chloride the duration of the anæsthesia may be lengthened. If the solutions are mixed and used at once, the potassium sulphate does not cause a precipitate with the calcium chloride. The epinephrin should not be added until the solution is ready for use, as it is very unstable when in contact with other organic substances. Epinephrin solutions which have turned pinkish

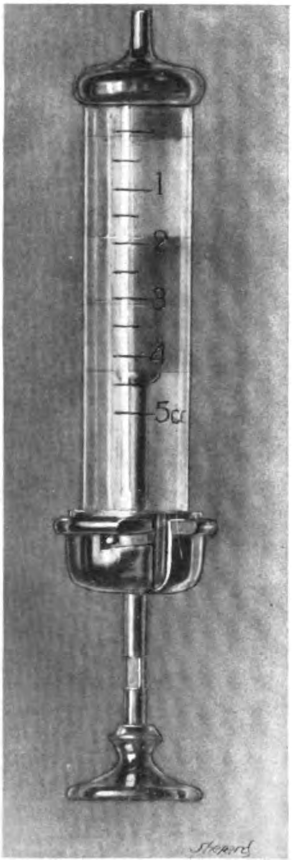


FIG. 10a. 5 CCM. RECORD SYRINGE.

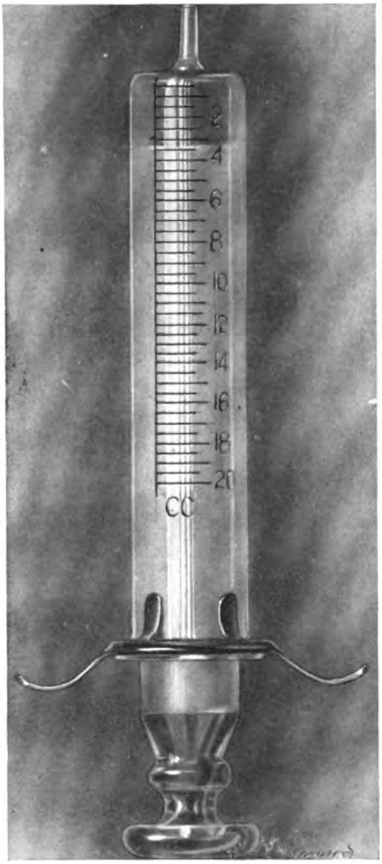


FIG. 10b. 20 CCM. GLASS LUER SYRINGE.

or yellowish should not be used. The author has used as much as 300 ccm. of this solution in adults without toxic symptoms.

When the 1 per cent solution of the anæsthetic is diluted by the addition of the other solutions mentioned, it becomes reduced to a 0.5 per cent or a 0.35 per cent solution, according to the amount of the other solutions used; such a dilution is strong enough for ordinary work. When it is desired to block large nerve trunks with a small amount of the fluid the original anæsthetic solution may be increased to 2 per cent.

Method of injection. For purposes of injection, one should have a glass hypodermic syringe, with fine sharp hypodermic needles, and a 10 ccm. or 20 ccm. Luer or Record syringe with some 19-gauge needles, 5 - 12 cm. long (Figs. 10a, b). With a hypodermic syringe and a very fine sharp needle, so as to reduce the pain of the initial needle-prick to a minimum, a small wheal is made in the skin at the desired point. One of the larger needles selected for the particular purpose is now introduced through the anæsthetic wheal. The large needles should always be introduced detached from the syringe, so that should the point of the needle enter a blood vessel the fact may be readily recognized by the escape of blood. It is so important that this rule be followed in certain regions of the body that the only safe way is to make the rule universal. The author knows of one sudden death caused by the injection of the fluid directly into the circulation by reason of failure to observe this simple rule.

If the infiltration method is to be used, the needle may be introduced through the wheal and passed along the subcutaneous or deeper tissues to the extent desired, when, should no blood escape from the needle, the fluid may be injected slowly as the needle is withdrawn. The fluid should be injected slowly in order that it may diffuse itself uniformly through the tissues. Should the needle not be long enough to reach the distance desired, a second wheal may be made in the skin from within out, and the needle withdrawn and introduced through the second wheal, thus avoiding the pain of another needle puncture. After the subcutaneous layer has been infiltrated, the other layers may be treated in turn in the same manner until the entire thickness of the part to be operated on has been brought in contact with the fluid. With the infiltration method the anæsthesia is complete almost at once, provided the subcutaneous tissue immediately beneath the skin is thoroughly injected. It is not necessary to inject the skin itself, as the nerves entering it are quickly reached by diffusion.

In conduction anæsthesia, or nerve blocking, it is necessary to introduce the point of the needle down to the nerve trunk to be blocked. It is not necessary or as a rule desirable that the point of the needle penetrate the nerve, as in so doing it may injure the nerve fibers. The fluid, however, must be brought in immediate contact with the nerve, so that it may diffuse itself into it, otherwise the anæsthesia will not be complete. This method is called paraneural injection.

In order to block the nerves successfully, one must have an accurate knowledge of their location and of the best point at which to reach them, as well as a knowledge of their distribution or the exact areas and structures supplied by them. Many of the nerve trunks have a layer of fascia lying just superficial to, or just beneath them, and if the fluid be deposited so that the fascia is interposed between it and the nerve, the anæsthesia will be incomplete or nil. It is essential, therefore, that one know exactly where the point of the needle is at the moment of injection.

When one is introducing a sharp needle into the tissues to any depth, it is a difficult matter to recognize the different layers through which the

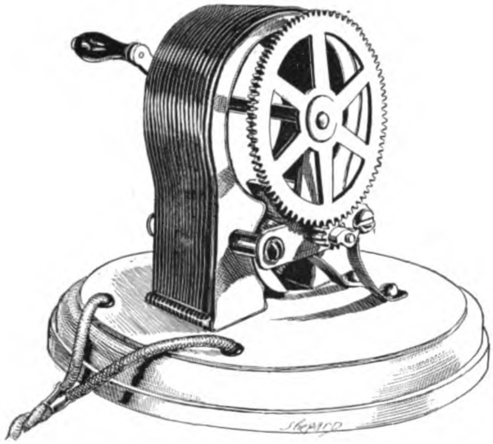


FIG. 11a. TOY TESLA DYNAMO.

needle passes. The recognition of the different layers is much facilitated by moving the needle point back and forth laterally as it is introduced. The point of the needle, on passing through the skin, enters the subcutaneous fat, which is so loose that the needle may move from side to side very easily. If the needle be slowly advanced as it is moved back and forth, the point may be felt to scratch the fascia, and thus identify it before penetrating it. If the needle then enter muscle, it may be pushed on until it is felt to scratch the next layer of fascia. By following this method, one may have a clear idea of the location of the point of the needle. It is well to practice injecting nerve trunks on a fresh cadaver with a colored fluid, such as methylene blue, and then to cut down and see if the fluid has stained the nerve.

Some of the nerves, such as the sciatic, lie quite deep and, particularly in fleshy people, are not always easy to locate with the needle. To facilitate finding such nerves the author has made use of a very simple and inexpensive device. This consists of a small toy Tesla dynamo (Fig. 11a), and a long hollow needle insulated to within 2 or 3 mm. of the point (Fig. 11b). To the negative pole is attached by a wire a small copper electrode, and to the positive pole a small coupler to fit the socket end of the needle. In locating a nerve, such as the great sciatic, the copper electrode wrapped in wet absorbent cotton is placed on the calf of the leg or any other indifferent part of the body, and the insulated needle with the positive wire attached introduced in the direction of the nerve. When the point of the needle reaches the approximate location of the nerve, an assistant slowly turns the crank of the dynamo. Every "click" of the instrument causes a very slight electric discharge. When the non-insulated point of the needle comes in contact with the nerve the slight electric discharge causes a contraction of the muscles supplied by the nerve.

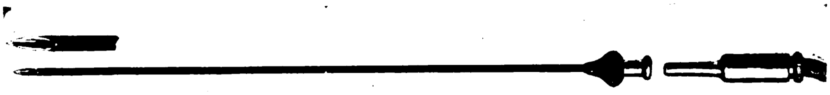


FIG. 11b. INSULATED NEEDLE.

After the contact of the point of the needle with the nerve has been thus established the wire is detached and the anæsthetizing fluid injected directly on the nerve. With this simple device any mixed or motor nerve may be readily located by the muscular contraction produced, and purely sensory nerves by the sensation produced by the electric discharge. Of course, any other form of apparatus may be used to generate the electricity, but the one mentioned is simple, inexpensive, dependable, and efficient. Care should be taken not to injure the nerve with the needle, as permanent damage may be done.

Preparation of the patient. Patients require no special preparation for operations under local anæsthesia. The administration of morphine or scopolamine before the operation for the purpose of diminishing or preventing so-called psychic shock is not only unnecessary, but as a rule inadvisable. There should be no harmful psychic effect, and if properly handled the patient will go to the operating table without fear of being hurt. The horror of an operation has its origin, as a rule, in the fear of pain, and when this fear of pain has been eliminated there will be no unpleasant psychic effect. The confidence of the patient should be secured and he should be made to understand that there will be no pain connected with the operation. One should never surprise the patient by sticking him with a needle when he is not expecting it, nor should an attempt be made to cut the skin before the anæsthesia is complete. He should be informed of the particular sensations that he will experience about the field of the operation. There will be a sensation of numbness in the region blocked, a feeling of weight or slight pressure, and gross movements of the parts may be felt; but none of these sensations are in any degree painful, and when the patient expects them, he thinks nothing of them. If the patient should experience any pain, he should be instructed to mention it at once, for in the majority of cases sensation may be controlled completely by the injection of more of the anæsthetizing fluid. If the confidence of the patient is thus once secured, there will be no trouble, as he will have no fear. Many patients who are nervous and apprehensive before the operation is begun become perfectly composed when they realize that they have actually been cut without experiencing any sensation. It is very rare indeed that a patient is so nervous before the operation that it is advisable to give a hypodermic of morphine to quiet him, but occasionally it is desirable, if the operation is to be a long one, to give a small dose of morphine in order to mitigate somewhat the irksomeness of lying still so long in one position.

After-effects. If distilled water be injected into the skin, after the first few moments of slight anæsthesia, mild painful sensations at the point of injection will be experienced for quite a few minutes. However, if sodium chloride be added to the water in sufficient amount to make an isotonic solution, no after-pain will be experienced. If the sodium chloride be added in excess, so as to form a hypertonic solution, the injection will be painful and the pain will increase with the strength of the solution. If the procaine or apothesine solution be approximately isotonic, there will be no pain attending or following the injection. If an operation has been performed under local anæsthesia, when the effects of the anæsthetic have worn off and normal sensation has returned the wound will be sensitive and tender to the same degree that it would have been had it been produced without a local anæsthetic, or under a general anæsthetic, but no more so. This, however, cannot be considered an after-effect of the local anæsthetic. The solution already mentioned, containing the calcium and potassium salts, does not produce after-pain; there is no swelling or infiltration about the wound and no disturbance whatever in the healing process.

So far as the local anæsthetic itself is concerned, the general after-effects are practically nil. If considerable of the drug has been used about 5 per cent of the patients will experience some nausea, and rarely one may vomit; but as a rule, if there is no contra-indication, patients are able to partake of light food and drink on returning to their room after the operation. If morphine has been given previously to the operation, about 30 per cent will have nausea, many of them to the extent of vomiting, due to the morphine or to the combination of the morphine and the anæsthetic. On account of the greatly increased percentage of postoperative nausea and vomiting following the use of morphine, it is much better, as already stated, to omit the preliminary injection of morphine except in special cases.

Gas pains following abdominal operations under local anæsthesia are much less frequent and severe than after operations done under general anæsthesia. As gas pains are largely the result of a certain amount of traumatism incident to exposure and manipulation of the intestines and peritoneum, they are, to a considerable extent, independent of the anæsthetic used.

Advantages of local anæsthesia. The chief advantage of local over general anæsthesia lies in its greater safety. Deaths due to procaine (novocaine) have been very few and these have occurred where very strong solutions were used, or when the fluid was injected directly into the blood stream. The only case of death from novocaine, with which the author is familiar, occurred in the hands of a throat specialist who was about to remove the tonsils. The long needle attached to a syringe loaded with novocaine solution was thrust into the peritonsillar tissues and the fluid injected. The patient collapsed almost immediately and died in a few minutes. An autopsy revealed no other cause of death than the novocaine, which in all probability was injected directly into the circulation. If proper precautions are taken such an accident is not likely to happen. So far as the author has been able to learn, no deaths have occurred from the use of apothesine.

There are no disagreeable after-effects following the use of local anæsthesia, such as are common after general anæsthesia. Nausea if present at all is slight, and vomiting seldom occurs. There is a notable absence of the symptoms of shock and depression, and as a result convalescence is more rapid and patients are able to be up earlier. Even after quite severe operations, such as the removal of large goiters, there may be no disturbance whatsoever of the pulse rate or of the blood pressure. It is a great satisfaction for everyone concerned to see patients come from the operating room feeling as bright and cheerful as when they entered it. It is also a great comfort to many persons to know that they can be operated on without the necessity of losing consciousness. Many patients have a dread and fear of losing consciousness, and an operation that can be done without the loss of consciousness is looked upon as much less serious and less dangerous then one for which it is necessary to be put to sleep. The patient who is awake and conscious may often assist the operator by changing position, or by moving some particular part, or by talking to the operator during an extensive goiter operation, and thus assuring the operator that the recurrent laryngeal nerve is not being interfered with.

Postoperative pneumonia is much less frequent after local than after general anæsthesia, as there is not the bronchial irritation with excessive mucus formation so frequently seen after the use of ether, and as there is less danger of the patient's inhaling foreign substances into the lung. The author has had but one case of postoperative pneumonia in a thousand major operations done under local anæsthesia, and this followed an extensive goiter operation. The patient had great difficulty in clearing the trachea of the mucus, the presence of which is so common after such operations. Pneumonia developed on the third day, and the patient died. Postoperative renal complications do not occur as the result of local anæsthesia, as the substances used at present do not have any deleterious effect on the kidneys.

In operations on the face, head, and neck, it is a great advantage not to have the anæsthetist and his apparatus in the way of the operator.

Disadvantages and complications. It is difficult to point out any actual disadvantages of local anæsthesia when used in suitable cases. It seldom takes longer to prepare a patient for operation by the local method than it does by the general method. If there are several cases to be operated on, the assistant can have them prepared in advance so that they will be ready for the operator in turn, in which case no time will be lost. If the proper solution be used, there is no danger of the anæsthesia wearing off before the conclusion of the operation, as it can be made to last from three to four hours, or longer if desired. It occasionally happens that it becomes necessary to extend the operation beyond the blocked area, in which case the area must be enlarged, or, should this not be feasible, recourse must be had to gas or other forms of anæsthesia. In abdominal operations, the manipulation of the organs rarely causes the patient to retch or vomit, if the viscera are handled gently and carefully. If proper precautions are used in making the injections, toxic symptoms will be very rare indeed. In several thousand injections of novocaine (procaine) and apothesine, involving all parts of the body, the author has never seen serious toxic symptoms. Shortly after the injection of the solution the patient's face may become pale, due, in all probability, to the epinephrin, and occasionally he will say that he feels the heart beating or has a slight numb feeling throughout the body, but all of these symptoms are momentary and of no consequence. In a small percentage of cases there will be a slight feeling of nausea soon after the injection is started and before anæsthesia is sufficiently marked to begin operating. This preliminary nausea, which in the author's experience has occurred a little more frequently with apothesine than with procaine, soon passes away. Should sufficient drug accidentally be injected directly into the circulation, symptoms of marked depression or collapse will supervene. It should be met by lowering the patient's head and by the administration of stimulants, the best of which is ether given by inhalation.

Sloughing, when it occurs, is the result of infection, due to a failure to sterilize the solution properly during its preparation; to an infection of the wound at the time of operation, or to an already existing infection; or to the addition of too much epinephrin to the solution. In the former case the slough will be moist, while in the latter it will be dry and ischæmic. The only slough which has occurred in the author's practice was undoubtedly due to the addition of too much adrenalin to the solution. The sloughing occurred in the abdominal wall which had been infiltrated preliminary to an operation for the removal of fibroids. The slough gave rise to no symptoms, and its presence was not suspected until the dressings were removed at the end of ten days for the purpose of removing the stitches, when a perfectly dry, aseptic, triangular slough was found, involving the skin and subcutaneous tissues. The slough was removed and the wound edges drawn together, when healing took place without further incident.

TECHNIQUE OF REGIONAL ANÆSTHESIA

The region of the body to be operated on may be rendered anæsthetic by infiltration or by blocking. The best method to be employed will depend upon the particular region involved, and at times on the character of the operation to be done. If the area to be anæsthetized is small, it is simpler and easier as a rule to infiltrate than it is to block. To block successfully requires not only an accurate knowledge of the anatomy, but also of the physiology, of the particular nerves to be blocked. Some regions, owing to the accessibility of the nerve trunks supplying them, are easily blocked, while others, for the opposite reason, are best anæsthetized by infiltration. When one is operating on a region suitable for blocking, it is better to block if the operation is one the extent of which is not clearly defined; while on the other hand, for small delimited operations in the same region, it may be easier to infiltrate. In selecting the method to be used one should be guided by the particular operation to be done as well as by the anatomic relations of the part.

Head. Many operations on the head, whether involving the soft parts alone or the bony structures as well, may be done very satisfactorily under local anæsthesia. The head is supplied by the fifth cranial nerve and by branches of the cervical plexus. It may be subdivided bilaterally into three regions, the anterior, lateral, and posterior. The anterior or frontal region is supplied by the supra-orbital and the supratrochlear nerves, branches of the first division of the fifth cranial nerve; the lateral or temporoparietal region, by the auriculotemporal nerve, a branch of the third division of the fifth; and the posterior or occipital

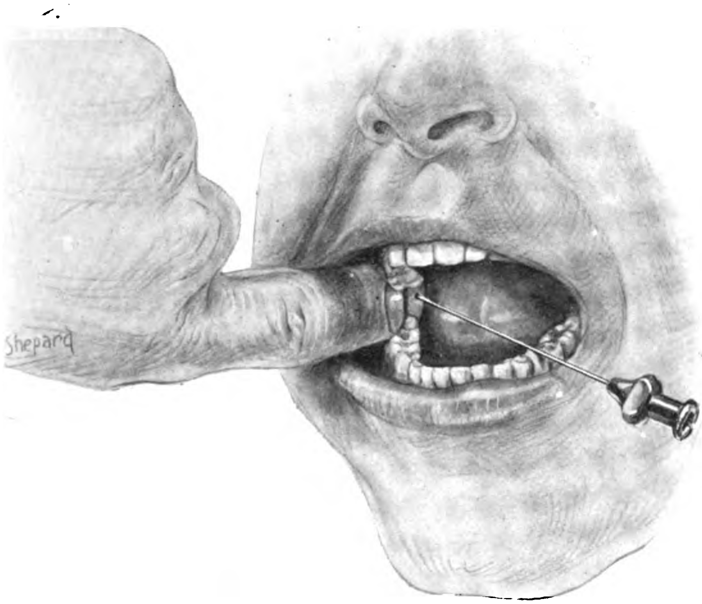


FIG. 12a. POINT FOR INTRODUCTION OF NEEDLE FOR BLOCKING MANDIBULAR NERVE.

region, by the occipitalis major and minor, and the auricularis magnus. These regions are not sharply outlined, as there is some overlapping of the nerve supply. The line separating the two lateral halves is more sharply defined, and if the operation is to extend across the midline both sides must be blocked. The supra-orbital nerve is easily reached as it escapes from the supra-orbital foramen; the supratrochlear as it winds over the orbital border to the inner side of the supra-orbital foramen; the auriculotemporal nerve, at a point between the temporal artery and the tragus of the ear just above the zygoma; the occipitalis major may be reached as it perforates the attachment of the trapezius to the superior curved line a little external to the occipital protuberance; and the occipitalis minor and auricularis magnus as they pass around the posterior border of the upper third of the sternocleidomastoid muscle.

The nerves in the scalp lie between the superficial and the deep fascia, or the epicranial aponeurosis, and the fluid should be injected into this space to infiltrate the scalp. The integument, or hairy portion of the scalp, is quite dense and not easily infiltrated. When the scalp has been anæsthetized, such operations as the removal of wens, angiomata, or

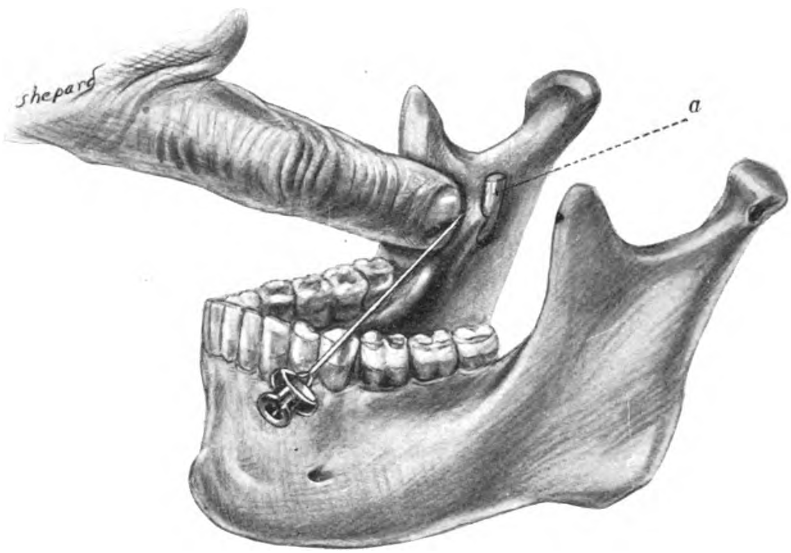


FIG. 12b. POINT OF NEEDLE APPROACHING MANDIBULAR NERVE. *a*, Inferior alveolar nerve.

other tumors, and the repair of injuries may be done without pain. The bones of the vault of the cranium are not sensitive; hence, by blocking or infiltrating a sufficiently large area either temporal or suboccipital trephining may be done for injury or for decompression purposes. The chisel and mallet should not be used too vigorously on account of the jarring. The dura mater is not sensitive to trauma under ordinary conditions, and may be incised without pain, as may also the brain itself.

Face. The face is supplied by the second and third branches of the fifth and by branches of the auricularis magnus and the superficialis colli; the latter nerves supply the region over the parotid gland, the angle of the jaw, and the area beneath the angle of the jaw and chin. If the operation involves the soft parts only and lies within the area supplied by the infra-orbital and the mental nerves, anæsthesia may be produced by injecting these nerves as they escape from their respective foramina. The needle may be introduced either through the mucous membrane of the mouth or through the skin. If the field of the operation extends beyond the area supplied by the nerves mentioned, the auricularis magnus and superficialis colli must be blocked as well. As there is considerable overlapping of the nerve supply, it may be necessary to block these nerves on both sides. In operations on the lower jaw, the third branch of the fifth must be blocked, either on one or both sides, just before it enters the internal dental foramen on the inner surface of the ramus. To reach this nerve a long needle is introduced at a point about 1 cm. above the grinding surface of the last molar tooth, and about 1 cm. posterior to the internal oblique line (Fig. 12a). The needle should not be on a line directly from before backward, but obliquely, so that when the tip of the needle is at the point just mentioned the needle will lie in a line crossing the second molar tooth of the opposite side. The needle should be introduced about 1.5 cm. in a posterior and slightly upward direction. It should be remembered that the inner surface of the ramus often bulges slightly just anterior to the dental foramen (Fig. 12b), and care should be taken that the point of the needle passes over this bulging. From 4 to 5 ccm. of the solution should be injected. Anæsthesia will be complete in ten minutes, and it will extend as far forward as the incisor teeth.

The second branch of the fifth nerve may be reached by the orbital or the lateral route. In the orbital route the point of the needle is introduced at the inferior external angle of the orbital border. The outer end of the needle is elevated so that the point follows along the inferolateral wall of the orbit until it reaches the sphenomaxillary fissure, when the outer end of the needle is carried downward and outward until the projected line of the needle in the horizontal plane passes through the upper part of the pinna of the ear. The needle is then pushed on through the sphenomaxillary fossa to a depth of about 5 cm. from the skin, when it should impinge against the sphenoid bone at the foramen rotundum. This is a difficult route to follow and there is great danger of the point of the needle going wrong.

There are two lateral routes. In one the point of the needle is introduced beneath the anterior end of the zygoma and passed in a direction inward, upward, and slightly backward, until it comes in contact with the posterior surface of the superior maxilla, which it follows until it enters the pterygopalatine fossa. At a depth of 4 - 5 cm. it will be found in close contact with the second branch of the fifth nerve.

In the second lateral route, which is the simplest and easiest way of reaching the nerve, the point of the needle is introduced just above the anterior end of the zygoma at the angle formed by the junction of the superior border of the zygoma and the malar bone (Fig. 13a). The needle is pushed directly inward until it strikes against the great wing of the sphenoid. The point of the needle is then depressed until it slips under the edge of the great wing of the sphenoid, when it will lie in the spheno-maxillary fossa, directly in contact with the maxillary nerve (Fig. 14). When the nerve is reached, the patient usually experiences a sensation of pain in the distribution of the nerve. About 2 ccm. of a 2 per cent solution of procaine or apothesine are sufficient to

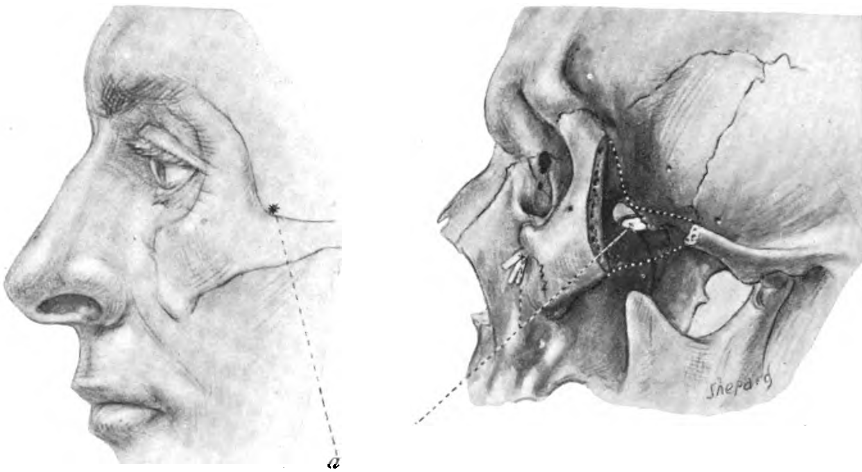


Fig. 13. INJECTION OF MAXILLARY BRANCH OF FIFTH NERVE. *a*, Point for introduction of needle. *b*, Maxillary branch of fifth nerve.

completely block the nerve. Both sides may be injected if necessary. If more extensive anæsthesia is desired, both the second and third branches of the nerve may be blocked, or even all three branches in the manner already explained, or the gasserian ganglion itself may be injected by passing the needle through the foramen ovale. To reach this foramen the point of the needle should be introduced on the cheek about 3 cm. back of the angle of the mouth (Fig. 15a). Guided by a finger in the mouth, so that the needle may not enter this cavity, the needle is pushed backward, inward, and upward. The direction which the point of the needle is taking is indicated by that portion of the needle which extends beyond the surface. Viewed directly from in front, the projected line of the needle should pass through the pupil of the eye of the same side (Fig.

15b.) Viewed from the side, the projected line of the needle should pass through the center of the zygoma. If the needle be made to follow these two projected lines, the point will impinge against the inferior surface of the great wing of the sphenoid directly in front of the foramen ovale (Fig. 15c). In order not to go astray it is essential that the point of the needle strike against this bony surface. The point of the needle is then slowly depressed, and gently forced along the bone until it is felt to enter the foramen. Along this route, the bone lies at a depth of 5 – 6 cm. When the point of the needle is felt to enter the foramen it should be pushed along the canal for a distance of 1 – 1.5 cm., when it will lie

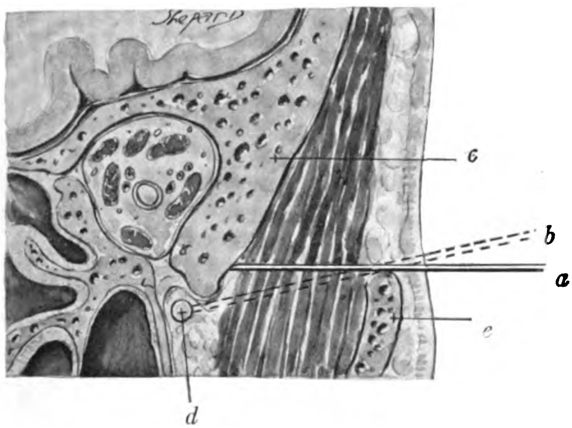


FIG. 14. INJECTION OF MAXILLARY BRANCH OF FIFTH NERVE. *a*, Direction for introducing needle. *b*, Point of needle to be depressed upon striking *c*, sphenoid bone. *d*, Maxillary branch of fifth nerve. *e*, Zygoma.

at the ganglion. If no fluid or blood escape from the needle, from 0.5 – 1 ccm. of a 2 per cent solution may be injected very slowly. Anæsthesia of all three branches of the fifth nerve quickly follows and is complete in 3 – 5 minutes. If the needle strikes the base of the skull too far back, there is danger of injuring the eustachian tube or the internal carotid artery. This is best avoided by keeping the outer end of the needle depressed far enough so that the projected line of the needle, viewed from the side, passes anteriorly to the middle point of the zygoma. When one is blocking either the branches of the fifth or the ganglion, it is a great advantage to have a skull at hand for comparison. A needle used should have a mark on it of known distance from the end, so that the exact depth of the point may at all times be known. While as yet no serious accidents seem to have occurred from injecting the ganglion, more extended experience is necessary in order to determine what, if any, the real risks of the procedure are. Under the anæsthesia thus obtained any operation involving the soft parts or bony structures of the face may be performed.

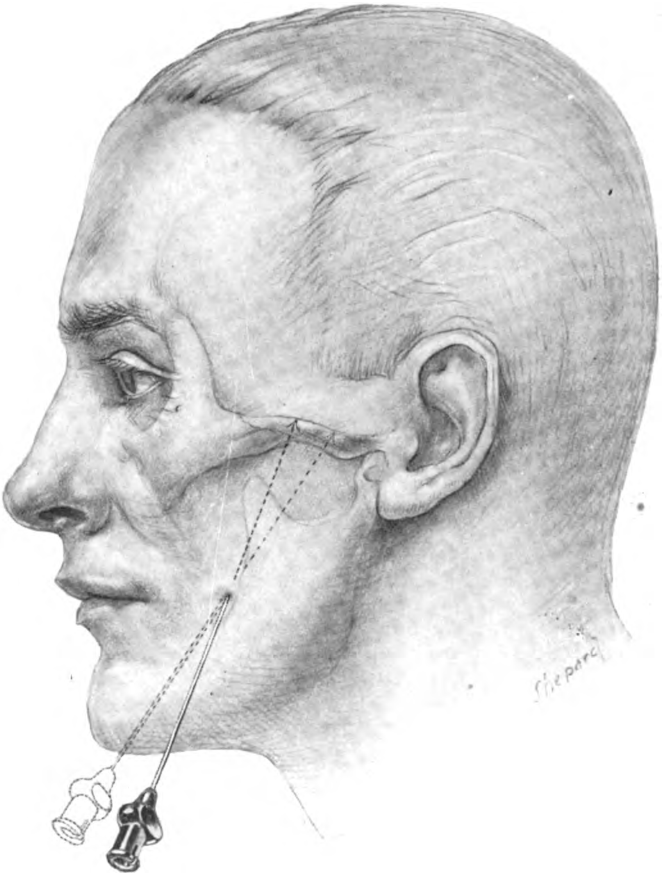


FIG. 15a. INJECTION OF GASSERIAN GANGLION. Point for introduction of needle and direction of needle viewed from the side.

The advantage of being able to dispense with an anæsthetist in operations about the face is very great, and warrants further experiments with this method of rendering the face anæsthetic.

The anterior half of the tongue is easily rendered anæsthetic by blocking the lingual nerves as they pass along the sides of the base of the tongue. The nerves are quite superficial in this location. If the operation is to involve the posterior half, the base of the tongue, which is supplied by the glossopharyngeal and the vagus, should be infiltrated.

Neck. The anterior and lateral regions of the neck, from the chin to the sternum and from the mastoid to the acromion, are supplied by

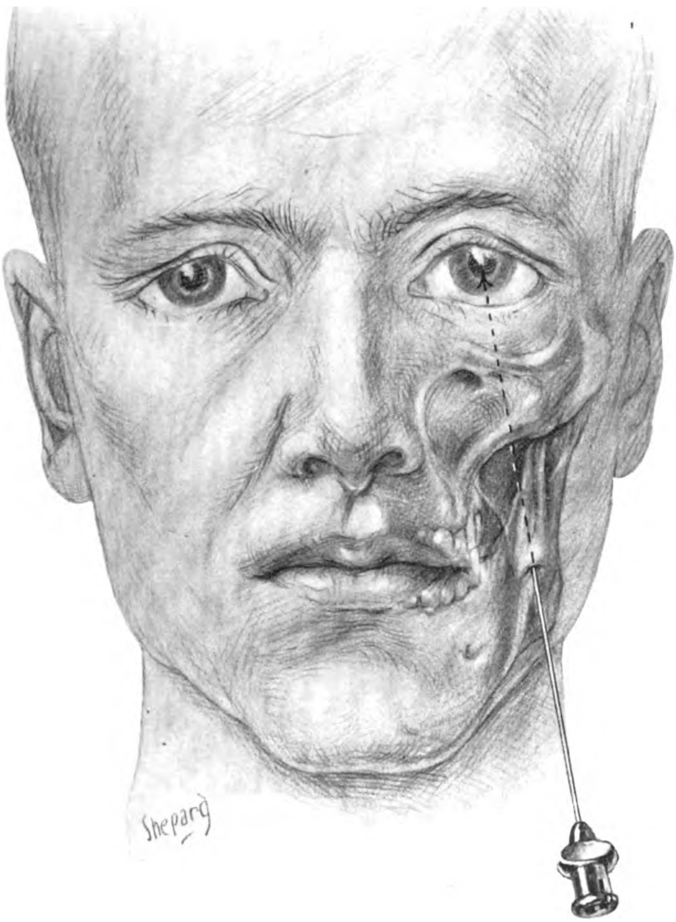


Fig. 15b. INJECTION OF GASSERIAN GANGLION. Line of needle viewed from front.

branches of the cervical plexus,—the occipitalis minor, auricularis magnus, superficialis colli, and the anterior, middle, and posterior supraclavicular nerves. These nerves may all be reached at the posterior border of the sternocleidomastoid muscle. The needle should be introduced just above and posterior to the crossing of the external jugular vein and the posterior border of the sternocleidomastoid (Fig. 16). The anæsthetic must be injected beneath the deep fascia. By directing the needle forward beneath the deep fascia, the superficialis colli is reached and by directing it upward, just beneath the posterior border of the muscle, the occipitalis minor is reached. The auricularis magnus soon perforates the deep fascia

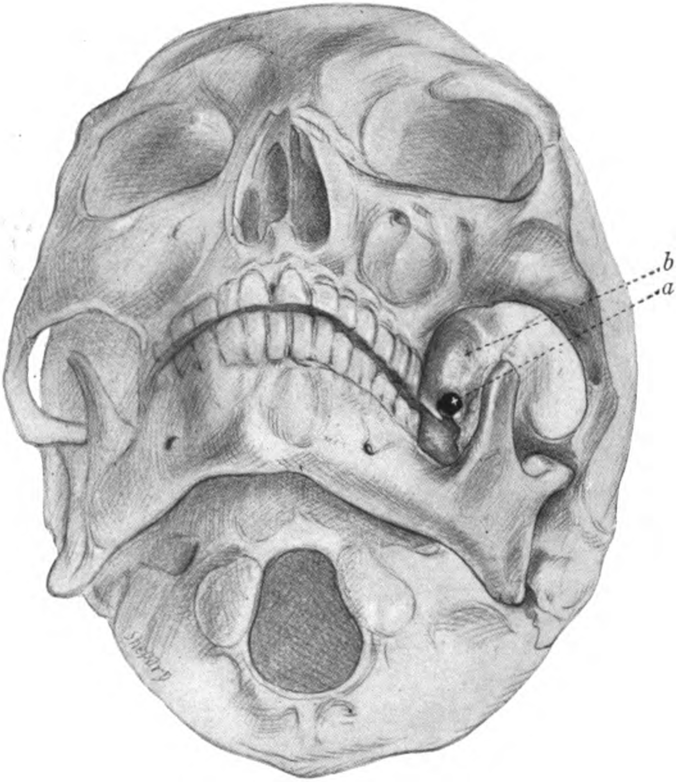


FIG. 15C. INJECTION OF GASSERIAN GANGLION. *a,* Foramen ovale. *b,* Inferior surface of great wing of sphenoid.

and lies a little anterior to the occipitalis minor. By directing the needle downward and slightly backward, the supraclavicular branches are reached. To block all of these nerves requires the injection of 15 – 25 ccm. of a 1 – 1.5 per cent solution of procaine or apothesine. Only those nerves need be blocked which supply the area to be operated on. If the operation extends across the midline, both sides should be blocked. If the deep structures of the upper part of the neck are to be invaded by the operation, it is well to block the superior laryngeal nerve behind and below the great cornu of the hyoid bone. Blocking the neck in this manner is a very satisfactory procedure, and permits the painless performance of almost any operation in the anterolateral region of the neck, such as removal of tubercular glands, tumors, goiters, and the performance of tracheotomy, laryngectomy, ligation of arteries, plastic operations, etc. Blood vessels are sensitive; consequently the ligation of the

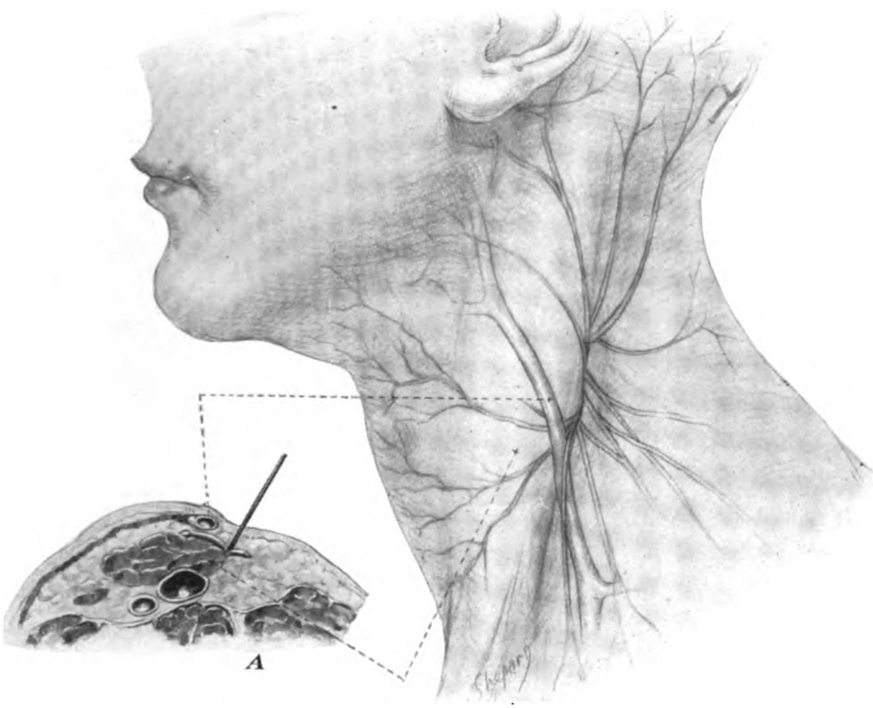


FIG. 16. POINT FOR INTRODUCTION OF NEEDLE FOR BLOCKING OF CERVICAL PLEXUS.

vessels entering the superior pole of the thyroid is slightly painful, unless the superior laryngeal nerve is blocked as already mentioned. Laryngectomy under local anæsthesia is a comparatively simple operation on account of the absence of the anæsthetist and of all the troubles that usually accompany the giving of a general anæsthetic for this operation. The operation is painless until the pharynx, which is supplied by the glossopharyngeal and the vagus, is reached. A little infiltration at this point renders the area anæsthetic and permits the completion of the operation without pain. When the supraclavicular nerves are blocked, any operation on the top of the shoulder and the supraclavicular region, including operations on the clavicle itself, may be performed.

Upper extremity. The upper extremity may be rendered anæsthetic by blocking the brachial plexus in the neck just above the clavicle. If the blocking is successful the anæsthesia is complete, with the excep-

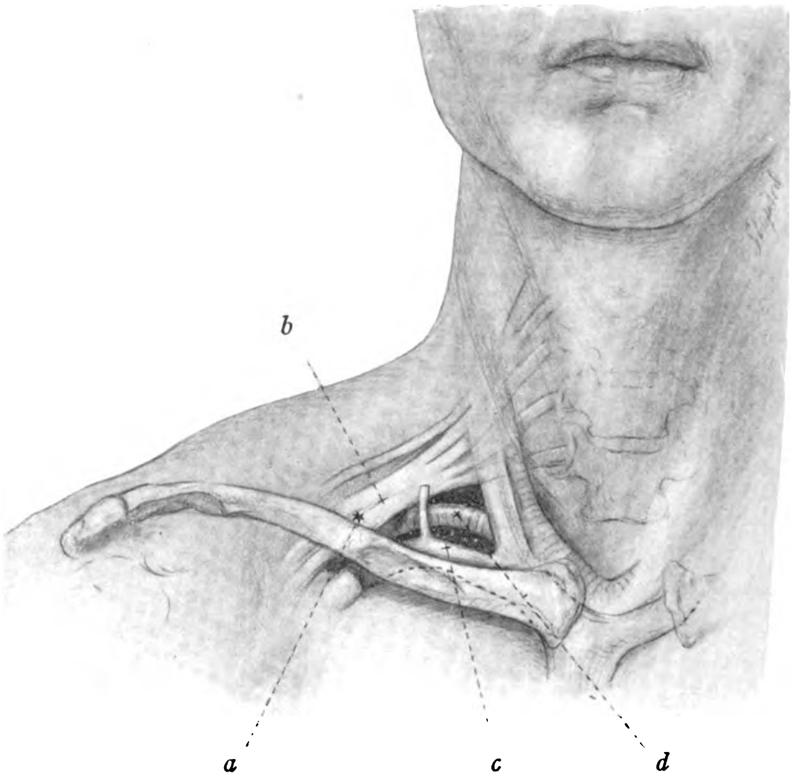


FIG. 17. SITE OF INJECTION OF BRACHIAL PLEXUS. *a,* Point for introducing needle. *b,* Brachial plexus. *c,* Subclavian vein. *d,* Subclavian artery.

tion of a small area on the inner side of the arm, which is supplied by the intercostohumeral nerve, and the area about the shoulder, which is supplied by branches of the cervical plexus. Owing to the intimate manner in which the nerve trunks in the axilla are surrounded by blood vessels, blocking of the trunks in this region, as described by Herschel (*Verhandl. d. Deutsch. Gesellsch. f. Chir.*, 1912, xli, 348), is not to be recommended on account of the danger of injuring the vessels. In the blocking of the

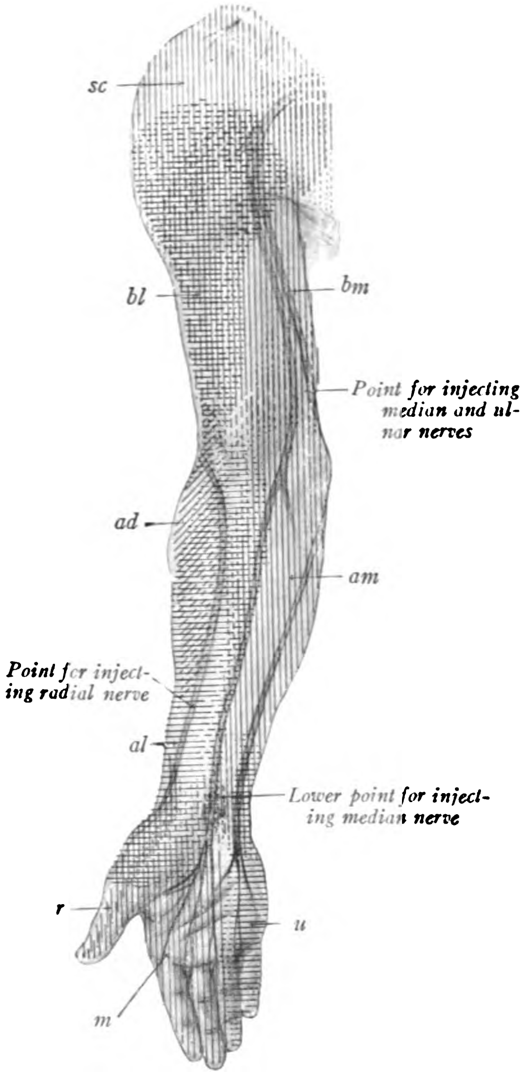


FIG. 18.

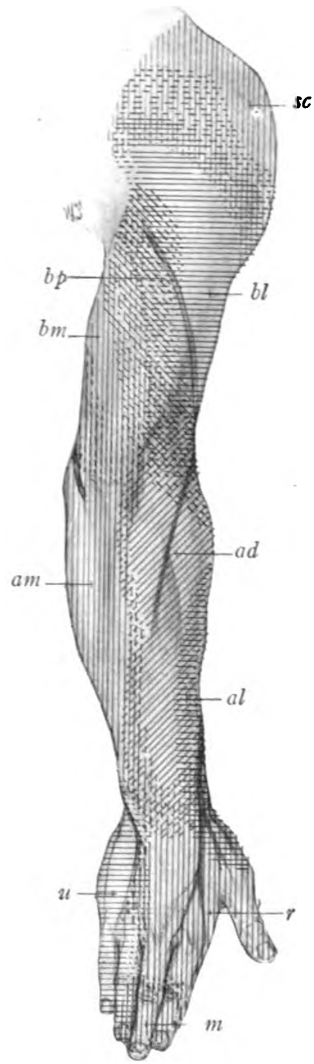


FIG. 19.

FIGS. 18 AND 19. NERVES OF UPPER EXTREMITY. *ad,* N. cutaneus antibrachii dorsalis (blue oblique). *al,* N. cutaneus antibrachii lateralis (red transverse). *am,* N. cutaneus antibrachii medialis (black vertical). *bl,* N. cutaneus brachii lateralis (blue transverse). *bm,* N. cutaneus brachii medialis (red vertical). *bp,* N. cutaneus brachii posterior (red oblique). *m,* N. medianus (red vertical). *r,* R. superficialis n. radialis (blue vertical). *sc,* Nn. supraclaviculares (black vertical). *u,* N. ulnaris (black transverse).

plexus above the clavicle, the method of Kulenkampf (*Centralbl. f. Chir.*, 1911, xxxviii, 1336) is the one usually followed. The injection may be made with the patient sitting or lying. In the sitting position, the shoulder and the clavicle are lower and the plexus more easily reached. If the injection is to be made with the patient lying, the shoulder should be drawn downward as much as possible. The subclavian artery is identified by palpation. A small wheal is made in the skin just above the middle of the clavicle, and external to the external jugular vein (Fig. 17). A small long needle is introduced through the wheal and passed in a direction backward, inward, and slightly downward, so that the line of projection would strike the second dorsal spinous process. The point of the needle will meet the plexus above the artery as the cords are about to cross the first rib. When the needle comes in contact with the nerves, the patient will experience paræsthesia in the region of distribution of the particular nerve touched. The use of the insulated needle and the small electric dynamo, already mentioned, will be of great assistance in locating nerves. When the needle is in contact with the cords, about 10 – 15 ccm. of a 2 per cent solution should be injected. Anæsthesia comes on slowly and is complete as a rule in from ten to fifteen minutes. It is advisable to allow the needle to remain *in situ* until it is certain that the anæsthesia is going to be complete. At the end of a few minutes, should it appear that the anæsthesia is not going to be sufficient, more of the solution may be injected without the necessity of re-introducing the needle. Blocking the plexus is not always an easy matter, and some experience is necessary in order to pass the needle to the right spot. The most difficult portion of the plexus to reach is the lower cord. The tendency is to pass the needle too high and too far out, on account of the fear of injuring the artery. While puncturing the artery is not a desirable thing to do, it has not so far been followed by any serious consequences. Of course, the needle should be introduced detached from the syringe, so that in case a vessel be punctured the escape of blood will give warning, and the injection of the solution into the circulation be obviated. Care must also be taken not to injure the pleura or lung by passing the needle too low and too far inward. In operations involving only a limited area of the arm or forearm it is better to block off the field by infiltration, and reserve the plexus blocking for more extensive operations, amputations, etc. In operations on the hand the ulnar and median nerves may be blocked in the lower part of the arm just above the elbow, where they both lie just beneath the deep fascia, or the ulnar nerve may be blocked back of the internal condyle of the humerus, and the median in the forearm a short distance above the wrist, where it lies in the midline beneath the tendon of the palmaris longus (Fig. 18).

The radial nerve may be reached 6 - 8 cm. above the wrist, where it lies external to the radial vessels beneath the tendon of the supinator longus muscle, or it may be reached just above the elbow where it lies rather deeply between the supinator longus and the brachialis anticus. Blocking in the latter position has the advantage of including the posterior interosseous nerve. Operations on the fingers, including amputations, may be done by injecting the nerves at the junction of the lateral and the anterior and posterior surfaces at the base of the finger.

Lower extremity. The lower extremity is supplied by the great sciatic, the small sciatic, the femoral (anterior crural), the lateral cutaneous, and the obturator nerves. The ilio-inguinal and the genito-crural supply a small area on the upper and inner part of the thigh. Some branches of the genito-crural, communicating with the middle cutaneous branches of the femoral nerve help to supply the skin as far down as the middle of the anterior aspect of the thigh.

If the entire extremity is to be anæsthetized, all of these nerves must be blocked. In blocking the great sciatic, the femoral, and the obturator nerves, the insulated needle and the little dynamo previously mentioned are very useful. To block the great sciatic, an insulated needle should be introduced at a point midway between the tuberosity of the ischium and the great trochanter, and pushed slowly inward (Fig. 20). The nerve lies at a considerable depth, being beneath the gluteus maximus and the plane of the hamstring tendons. When the point of the needle touches the nerve and the electric current is turned on, a contraction of the muscles supplied by the nerve takes place. The wire should then be disconnected from the needle and the solution injected immediately on the nerve. When an ordinary needle is used without the electric current, is is more difficult to find the nerve, particularly in a large fleshy thigh. The nerve is recognized by the paræsthesia complained of by the patient when it is touched by the needle. The small sciatic may be reached at the inferior border of the gluteus maximus, just external to the tuberos-

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FIGS. 20 AND 21. NERVES OF LOWER EXTREMITY. *ci*, N. clunium inferior medialis (blue transverse). *cm*, Nn. clunium medii (red vertical). *cs*, Nn. clunium superiores (red transverse). *fa*, R. cutanei ant. n. femoralis (red transverse). *fl*, N. cutaneus femoris lateralis (black vertical). *fp*, N. cutaneus femoris posterior (blue vertical). *ih*, R. cutanei laterales nn. intercostalis xii et iliohypogastrici (red oblique). *ii*, Nn. ilio-inguinalis et spermaticus externus (red oblique). *li*, N. lumbo-inguinalis (red vertical). *o*, R. cutaneus n. obturatorii (black transverse). *pl*, Nn. plantares (red vertical). *pp*, N. peronæus profundus (red transverse). *ps*, N. peronæus superficialis (blue vertical). *sa*, R. cutanei cruris mediales n. sapheni (red oblique). *sl*, N. cutaneus suræ lateralis (blue transverse). *su*, N. suralis (blue oblique). *t*, R. calcanei mediales n. tibialis (blue transverse).

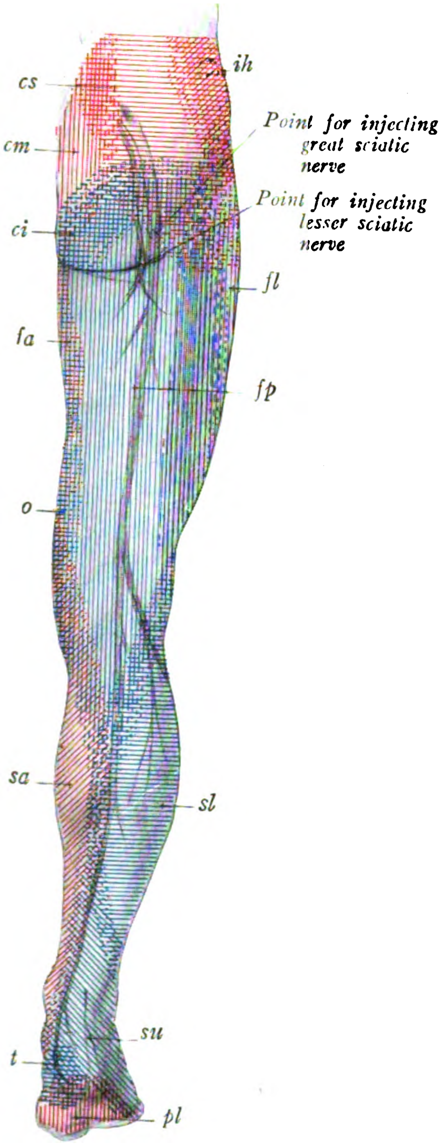
ih
cs
Point for injecting great sciatic nerve
cm
Point for injecting lesser sciatic nerve
ci
fl
fa
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FIG. 20.

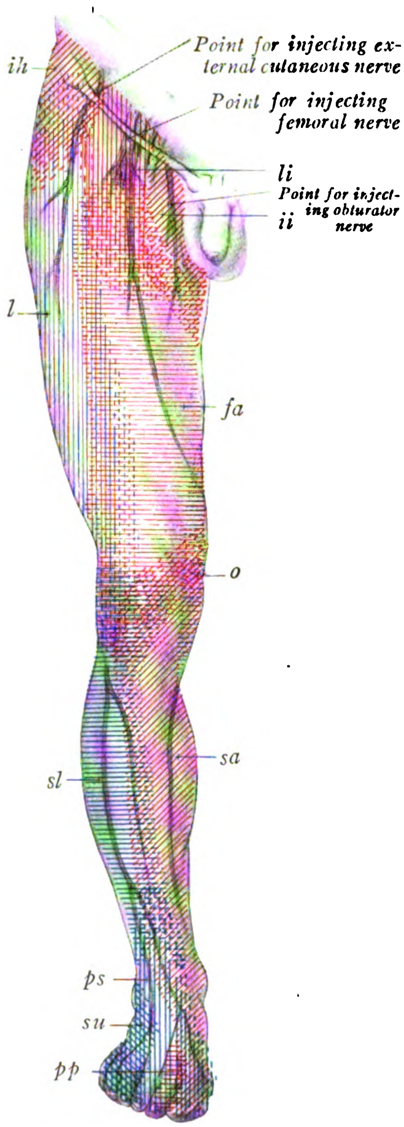
Point for injecting external cutaneous nerve
ih
Point for injecting femoral nerve
li
Point for injecting obturator nerve
ii
l
fa
o
sa
sl
ps
su
pp

FIG. 21.

ity of the ischium, where it lies beneath the fascia lata. The femoral nerve makes its exit from the pelvis beneath Poupart's ligament about 1 cm. to the outer side of the femoral artery (Fig. 21). It lies beneath the iliac fascia covering the psoas muscle at this point and occasionally it is buried slightly in the muscle. To reach the nerve the finger should be placed on the femoral artery to identify it, and the needle introduced just below Poupart's ligament and 1 cm. to the outer side of the artery. The point of the needle must lie beneath the fascia covering the psoas muscle. If the electric needle is used, when the point of the needle touches the nerve contraction of the muscles supplied by the nerve takes place. If an ordinary needle is used, the patient will experience painful sensations down the leg when the nerve is touched. From 5 to 10 ccm. of a 2 per cent solution will produce complete anæsthesia. The lateral cutaneous nerve may be reached at a point just above Poupart's ligament and about 2 – 3 cm. internal to the anterior superior spinous process of the ilium. The needle should be directed slightly downward beneath the ligament and the fascia lata. The obturator nerve lies on the adductor brevis muscle, and is covered by the pectineus. The needle should be introduced about 3 cm. below and to the outer side of the spine of the pubis. It should pass through the fascia lata, and between the pectineus and the adductor longus to the adductor brevis, when it should be directed outward and slightly downward about 2 – 3 cm. If the electric needle be used, contraction of the adductor group of muscles will be produced when the needle touches the nerve. When all of the nerves mentioned have been blocked, any operation may be done on any part of the lower extremity. The author has amputated through the thigh a number of times under blocking, and has found the method particularly useful in amputations for gangrene in feeble persons. Obviously all of these nerves need not be blocked in all operations on the limb, as it is necessary to block only those supplying the area to be operated on. In operations on the foot, only the great sciatic and the femoral need be blocked, but if the operation is a minor one, such as the removal of bunions or the amputation of a toe, it is simpler and easier to do it under infiltration.

Operations on the trunk. The trunk may be subdivided into two portions, an upper and a lower. The upper includes the thorax, and the lower, the abdomen. In the upper portion, operations on the breast are the most common. The breast and the skin covering it are supplied by the intercostal nerves and the descending branches of the cervical plexus; the latter extend below the clavicle on the anterior wall of the chest often as far as the nipple. The intercostal nerves and the descending branches of the cervical plexus overlap somewhat, so that the line of demarcation on the skin is not sharply drawn.

Raising the breast for the removal of benign growths through the posterior surface may be done very readily under local anæsthesia. Anæsthesia may be produced by blocking the nerve supply at a distance from the field of operation, or by the infiltration method. In the latter method the line of incision, which should lie in the crease marking the junction of the breast with the chest wall, should be anæsthetized by subcutaneous infiltration. A long needle is then passed into the loose cellular space between the breast and the pectoral fascia, and from 15 to 20 ccm. of the solution injected. By rubbing the breast against the chest wall the fluid is caused to spread out in this space. The breast may now be raised up and the growth removed through its posterior surface without pain. The space left in the breast as a result of the removal of the growth should be closed by catgut suture, the breast returned to its normal location, and the wound closed in the usual way. The entire breast may be removed by this method in non-malignant cases, but when malignancy is present and the complete operation is demanded, the more extensive blocking method is desirable. The descending branches of the cervical plexus should be blocked in the neck at the point already mentioned, and the second, third, fourth, fifth, and sixth intercostal nerves blocked near the angle of the ribs. The axillary space may be infiltrated. With this extensive blocking, the entire breast with the pectoral muscles may be removed and the axilla thoroughly cleared out.

In resecting a rib, the intercostal nerve above and below the rib to be removed should be blocked near or just posterior to the angle. By blocking well back, the lateral cutaneous branches are included in the block. By blocking a sufficient number of nerves, thoracoplasty may be done for chronic empyema, pulmonary abscess, the removal of foreign bodies, etc. Local anæsthesia is of special value in operations on the chest, owing to the great danger of a general anæsthetic in many of these cases.

Laminectomy may be done by injecting on both sides of the spine beside the vertebra to be operated on. After the skin has been rendered anæsthetic by the subcutaneous injection of a 0.5 per cent solution, the needle should be introduced about 3 cm. lateral to the spinous processes and passed down to the intervertebral foramina, so as to reach the posterior branches of the nerves, which are given off soon after the nerves make their exit from the canal. As many of the posterior branches must be injected as may be necessary to include the region to be operated on. Of course both sides must be injected.

Operations on the abdomen. As the abdominal wall can be rendered anæsthetic at any point and over any sized area, almost any operation involving the wall itself can be done under local anæsthesia, and as the entire thickness of the wall can be anæsthetized, the abdominal cavity can be opened at any desired point without pain. The parietal peritoneum is acutely sensitive to all kinds of trauma, and an injury to the peritoneum is always made manifest by pain and by muscular rigidity over the site of the injury. This muscular rigidity is so characteristic of peritoneal irritation that, when the abdomen is being opened under local anæsthesia, the absence of rigidity and of intra-abdominal tension is conclusive evidence that the nerves supplying the peritoneum at the site of the operation are completely blocked. This relaxation of the abdominal muscles with absence of intra-abdominal tension is one of the most striking features of abdominal operations under local anæsthesia. Blocking of the abdominal wall, however, does not block the organs within, but fortunately many of these organs are not sensitive to ordinary trauma, so that much operative work may be done within the abdomen without pain by simply blocking the abdominal wall. If the wall, including of course the parietal peritoneum, is blocked, the abdomen may be opened and its contents thoroughly explored without pain, and there will be no tendency for the intestines to crowd out of the opening so long as no unblocked parietal peritoneum is injured, or violently pulled upon. The portion of peritoneum covering the posterior abdominal wall is just as truly parietal peritoneum as that covering the anterior wall, and it is just as sensitive. The omentum, stomach, small intestine, colon, liver, gall-bladder, and spleen are not sensitive to trauma. The mesentery is not sensitive until one approaches its root, or the posterior parietal peritoneum. The kidney is not sensitive, but the peritoneum anterior to it is, as are also the perirenal tissues. While the mesentery itself is not sensitive, traction on it causes pain, which as a rule is referred to the region of the umbilicus, or the epigastric region, and which is usually accompanied by a feeling of nausea. If the mesocolon or the meso-appendix is drawn on, the same kind of a pain in the epigastric region, with nausea, may be produced. The gall-bladder may be opened and stones removed from it without pain, but traction on the bladder or any manipulation of the bile ducts immediately causes pain by reason of the interference with the posterior parietal peritoneum. For the same reason, manipulations of the duodenum are painful, although the gut itself may be incised and stitched without giving rise to any sensation. The use of laparotomy sponges in the abdomen to pack off the intestines is painful on account of the pressure on the parietal peritoneum. If one but bears in mind the fundamental principles and does not do violence to them, one may do a great deal of work in the abdomen under local anæsthesia in a most satisfactory manner. Operations on the small intestine and on the stomach, gastro-enterostomy, appendectomy, cholecystotomy, colostomy, in the majority of cases may be done without pain, under local anæsthesia alone. If during any of these operations it should be found necessary to invade an unblocked area, the patient may be given gas for a few minutes until that part of the operation is finished, when the gas may be discontinued and the operation completed under the local anæsthetic. The distress or pain and nausea caused by drawing on the appendix and its mesentery may be prevented or arrested by injecting the root of the mesenteriolum. For an average incision, the abdominal wall may be

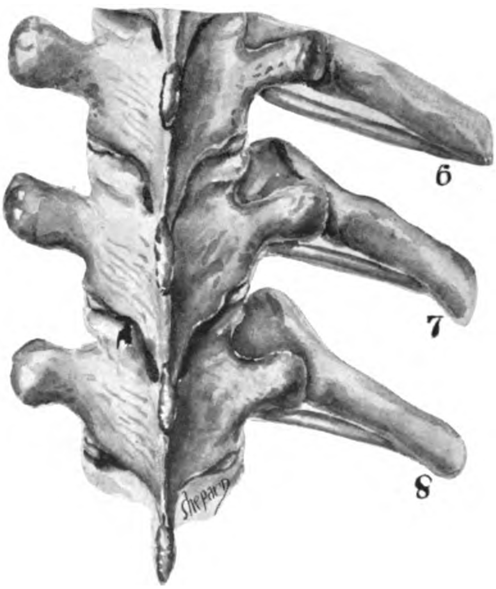

FIG. 22. INTERCOSTAL NERVES BETWEEN ANGLE OF RIBS AND SPINE.

rendered anæsthetic by the simple infiltration of the superficial and deep parts. If a wider area of anæsthesia is desired, the solution should be injected inside the sheath of the rectus muscle along its outer angle, as the intercostal nerves pierce the sheath at this point, and if blocked at this point on both sides the intervening space will be rendered anæsthetic. As the abdominal wall is supplied by the lower seven dorsal nerves, the entire wall may be anæsthetized by blocking these nerves on both sides at their exit from the spinal canal. It requires some practice to pass the needle down to the intervertebral foramina, and to deposit the solution exactly at the right spot. The dorsal or intercostal nerves are more easily reached by using the lower edge of the ribs as a guide than by attempting

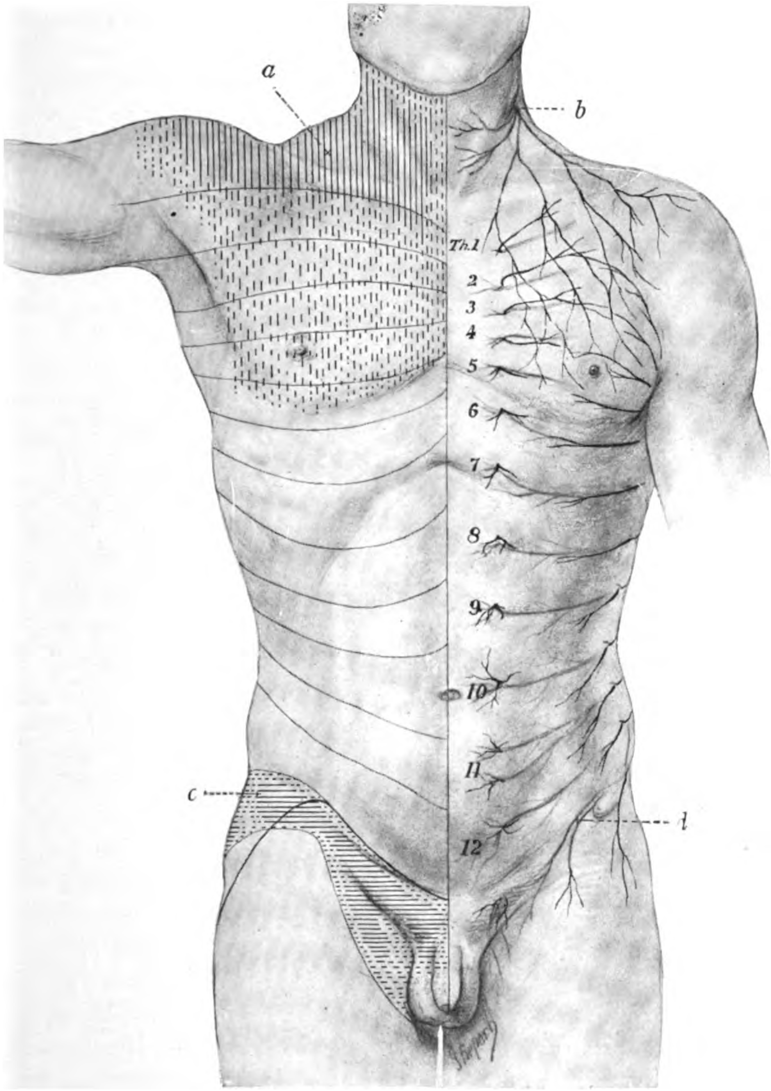

FIG. 23. CUTANEOUS NERVES OF CHEST AND ABDOMEN. *a*, Cutaneous distribution of supraclavicular nerves. *b*, Point for injecting cervical plexus. *c*, Cutaneous distribution of iliohypogastric and ilio-inguinal nerves. *d*, Point for injecting iliohypogastric and ilio-inguinal nerves.

to pass the needle directly down to the foramina. A wheal is made on either side of the midline posteriorly, about opposite the angle of the ribs, marking the upper limit of the nerves to be injected. Through this wheal the needle is introduced, and a small amount of a dilute solution injected into the skin from the inner side, opposite the angles of as many ribs as there are nerves to be blocked. This method renders subsequent puncturing of the skin painless. The needle is then introduced in an oblique direction inward and backward until it comes in contact with the lower edge of the rib, posterior to the angle. The point of the needle is then slightly depressed, and following the direction of the rib, pushed on toward the spinal column for a distance of 2 - 3 cm., when it will be found in contact with the nerve soon after its exit from the foramen (Fig. 22). From 3 to 5 ccm. of a 1 or 2 per cent solution should be injected about each nerve. If the nerves on both sides are blocked, an area in width corresponding to the number of nerves blocked will be anæsthetized, and the abdomen may be opened at any point within the anæsthetized zone (Fig. 23).

In operations on the gall-bladder, only the 6th, 7th, 8th, 9th, and 10th dorsal nerves on the right side need be blocked, while in removal of the appendix it is necessary to block only the 10th, 11th, and 12th dorsal. If one has not been entirely successful in reaching all the nerves desired at their exit, so that the anæsthesia is incomplete, it may be made complete by infiltrating the unanæsthetized spots with a dilute solution. Instead of using the paravertebral injection for removing the appendix, one may anæsthetize the area of operation by making a small wheal in the skin about 3 - 4 cm. above and internal to the anterior superior spine of the ilium. Through this wheal the needle is introduced in an oblique direction upward and backward into the space between the internal oblique and the transversalis muscles, and 4 - 5 ccm. of a 1 per cent solution injected at two or three points in this space. The needle is then withdrawn until the point is outside the external oblique, when it is introduced in an oblique direction downward and inward to the properitoneal space, and the same amount of the solution injected at two points. It is again withdrawn outside the external oblique, and then pushed along just beneath the skin in the direction of the proposed incision for a distance of 6-10 cm., as may be necessary, and a little of the solution deposited just beneath the skin as the needle is withdrawn. In about five minutes the abdomen may be opened along the line of anæsthesia without any pain. When the appendix is found, the root of its mesentery may be injected with a few cubic centimeters of the solution, and the appendix painlessly removed.

In operations on the kidney, the 10th, 11th, and 12th dorsal, and the 1st lumbar nerves should be blocked. If the kidney has to be separated from its surrounding capsule, it may be necessary to supplement the local anæsthesia with a little gas for a few minutes during this part of the operation.

In paravertebral work, the nearer the nerves are blocked to the intervertebral foramina, the better the anæsthesia, and if the blocking includes the branches communicating with the sympathetic ganglia, work on the viscera may be done without pain. As it is not always easy to bring the point of the needle to the exact spot desired, it is perhaps better to inject a larger amount of a dilute solution, for instance 10 – 15 ccm. of a 0.5 per cent solution, about each nerve rather than a smaller amount, 3 – 4 ccm., of a 1.5 or 2 per cent solution, as the chance of reaching all of the nerves is thus much greater.

Operations for the radical cure of inguinal hernia or for strangulated hernia may be done very readily under local anæsthesia. The region involved is supplied by the 11th and 12th dorsal and the 1st, and occasionally part of the 2nd, lumbar nerves. The paravertebral blocking of these nerves renders the entire region anæsthetic. As it is not always easy to reach the lumbar nerves at the foramina, the region may likewise be blocked by introducing the needle at a point about 3 cm. internal to, and slightly below, the anterior superior spine of the ilium, and passing it obliquely upward and backward between the internal oblique and the transversalis muscles to the crest of the ilium. From 15 to 20 ccm. of a 0.5 per cent solution injected at this point blocks the ilio-hypogastric, while the 12th dorsal is reached in the same space, but higher up from the point of introduction. The needle is then withdrawn just outside of the external oblique, when it is directed inward and slightly downward in the direction of Poupart's ligament and made to penetrate the external oblique, where the injection of 2 or 3 ccm. of the solution blocks the ilio-inguinal. The needle is then advanced toward the neck of the sac, where 3 or 4 ccm. of the solution are deposited; then it is withdrawn just outside of the external oblique. It should next be pushed along in the same direction, but just beneath the skin, as far as the spine of the pubis, where 3 or 4 ccm. of the solution are injected. The needle is then withdrawn entirely, and introduced over the spine of the pubis through the wheal made at that point, and passed down to Gimbernat's ligament, where from 5 – 10 ccm. of the solution are injected. The region will now be found thoroughly blocked, and any operation for inguinal hernia may be done without pain. Operations for femoral hernia, vasotomy and operations for hydrocele may be carried out under simple infiltration.

SACRAL ANÆSTHESIA

Blocking of the sacral plexus by intrasacral injection is one of the most satisfactory procedures in the field of local anæsthesia. As the spinal cord ends at the upper border of the second lumbar vertebra, and the central spinal canal ends in a sac at the second sacral segment, intrasacral injection produces a pure nerve blocking, and not a central anæsthesia. The sacral canal should be entered at the hiatus on the posterior surface of the caudal end. The size of this hiatus varies greatly. At times the posterior arches of the sacral segments are well formed and

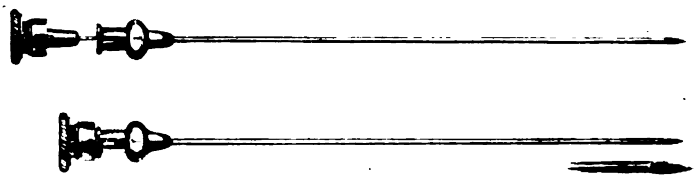

FIG. 24. SMALL TROCAR FOR INJECTING THE SACRAL CANAL.

quite complete, so that the opening into the sacral canal is at the end of the sacrum where it articulates with the coccyx. Again the posterior arches of the lower one or two segments may be defective, thus leaving an opening into the canal as much as 3 or 4 cm. in length. Sacra likewise vary greatly in their degree of curvature. As is well known, the curvature as a rule is greater in females than it is in males. Sacra are also frequently asymmetrical, so that the spines and the hiatus at the lower end are not exactly in the midline. All of these facts must be kept in mind when attempting to introduce the needle into the sacral canal. The author uses for this purpose a specially constructed needle, which in fact is a small trocar (Fig. 24), with its cannula of soft metal and its stylet of hard steel. The ordinary hollow needle is not safe to use for this purpose, as it is apt to break when being pushed through the dense ligamentous structure closing the hiatus, an accident which has happened to the author twice. The author introduces the needle in the following manner: The patient is placed on the right side, with the hips and knees well flexed. The posterior surface of the sacrum is carefully inspected and palpated to determine its degree of curvature and whether it is symmetrical or not. The sacrococcygeal junction is located by moving the coccyx, and its relation to the last spine noted. The distance between the last spine and the sacrococcygeal junction indicates the approximate length of the hiatus.

The hiatus when present may be recognized as a depression just below the last spine, with a well-defined edge of bone on either side. The hiatus is closed by a dense ligamentous structure. When the location of the hiatus is determined, a small wheal is made in the skin and the injection carried down to and into the dense ligamentous structure. The small tro-

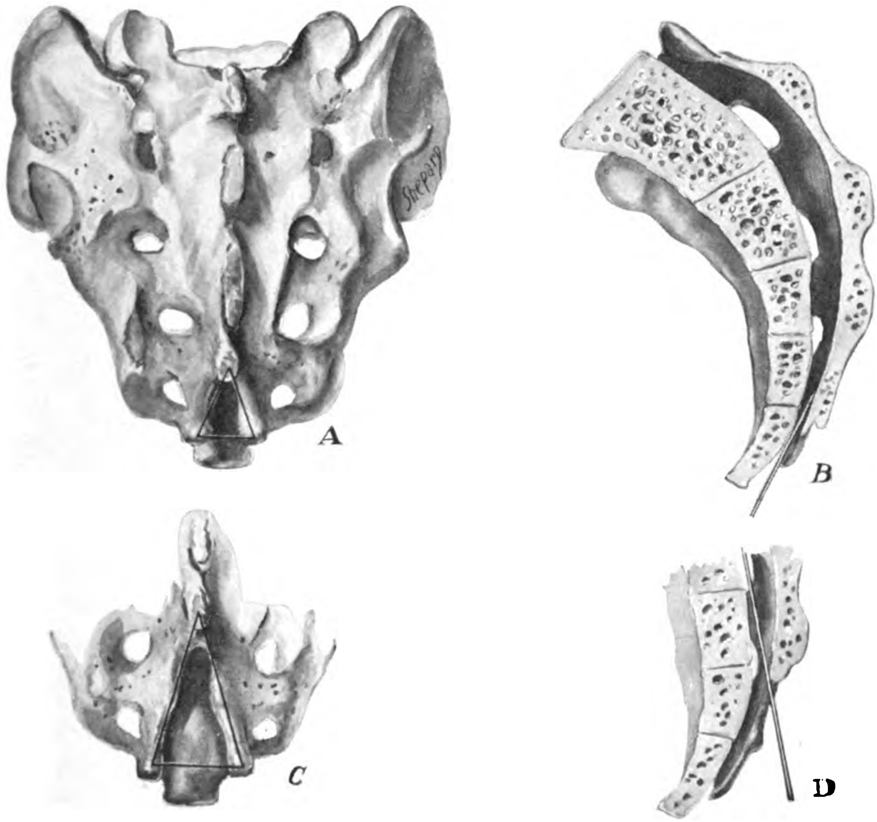

FIG. 25. TOPOGRAPHY OF SACRUM. *a*, Hiatus in posterior surface of sacrum. *b*, Direction of needle with small sacral hiatus. *c*, Hiatus in posterior surface of sacrum. *d*, Direction of needle with large sacral hiatus.

car is then introduced down to the dense structure, which is readily recognized by the sensation experienced as the trocar penetrates it, and pushed through it in the direction of the canal (Fig. 25). If it has been passed in the right direction, the trocar as it perforates the dense ligament will be felt to enter a free space. By pushing it on still further, one will feel the point of the trocar impinge against bone, which will be the posterior wall of the sacral canal. When the trocar is felt to pierce a dense ligament, enter a free space, then come in contact with bone, one may be sure that it is in the sacral canal. It is then withdrawn slightly and the stylet removed, leaving the cannula in place. If blood or spinal fluid escape from the cannula, it has entered one of the large veins or the spinal sac, and it should be slightly withdrawn, or its position changed, until the blood or fluid ceases to appear. After waiting a few seconds to be sure that nothing escapes from the cannula, one should inject about 10 ccm. of a 1.5 per cent solution. If the end of the cannula is in the sacral canal, the solution will flow in almost without resistance; but, on the other hand, if considerable resistance to the injection of the solution is felt, it is quite certain that the cannula is not in the canal. In about four or five minutes after injecting the 10 ccm., sensation should be tested. If anæsthesia is found gradually extending from the cannula toward the perineum, it is positive evidence that the cannula is in the proper place and the remainder of the solution may be injected. From 30 to 50 ccm. should be injected, depending upon the extent of the anæsthesia desired, and the cannula withdrawn. The patient may then be turned on the back and the hips elevated, permitting the fluid to gravitate further up the canal. The anæsthesia is usually complete in from 15 to 20 minutes, and involves the anus, rectum, perineum, urethra, penis, prostate and base of the bladder in the male, and the vagina, pudendal region, uterus, and, if sufficient solution has been used, the pelvic organs in the female. There will also be the usual saddle-shaped area extending over the buttocks and down the back of the thighs, the size of which will depend upon the amount of the solution used. Under this anæsthesia any operation involving the organs or regions mentioned may be performed without pain. Hæmorrhoids may be removed, fistulæ in ano operated on, and even complete proctectomy performed; strictures of the urethra may be divided, the prostate removed, either perineally or suprapubically (combined with local anæsthesia of the pubic region), and cystoscopic examinations made in painful cases. In the female, perineorraphy, colporraphy, trachelorraphy, curettage, and even vaginal hysterectomy may be performed under blocking of the sacral plexus. Blocking the plexus is greatly to be preferred to the infiltration method for the operations mentioned. In some minor operations, such as circumcision, it is unnecessary to block the plexus, as simple circular infiltration of the prepuce is sufficient.

CHAPTER IV

SPINAL ANÆSTHESIA

SPINAL anæsthesia (intradural anæsthesia, lumbar anæsthesia) is a form of conduction anæsthesia in which the nerve roots within the spinal canal are acted upon by a local anæsthetic introduced by a needle through the dura. The effect upon the cord proper is relatively slight, and the conducting paths within the cord may continue to functionate under spinal anæsthesia. Any efficient local anæsthetic may be used for spinal anæsthesia, but cocaine, eucaine, beta-eucaine, alypin, magnesium sulphate, and certain other local anæsthetics have been tried and discarded on account of untoward effects produced; and only stovaine, tropacocaine, and procaine need be considered.

To be efficient, the local anæsthetic must come in contact, in sufficient quantity and concentration, with all nerve roots supplying the segments invaded during the operation. While it is more important to abolish pain than motion, the associated action on the anterior nerve roots gives a relaxation that often greatly facilitates the work of the surgeon.

In 1888 J. Leonard Corning, of New York, attempted to influence the spinal cord by injecting between the vertebral spinous processes a solution of cocaine. It is probable that Corning's injections were really intradural, as he noticed motor and sensory loss in the lower extremities, conditions difficult to produce by small extradural injections. Although Corning suggested the feasibility of the method for the production of analgesia for surgical purposes, it was not until 1889 that August Bier, of Bonn, experimented upon himself and his assistant, and first deliberately produced spinal analgesia by an injection within the dura. The rapid and widespread adoption of the method, despite Bier's warnings, was followed by as rapid an abandonment, owing to unsolved technical difficulties, and the unpleasant and dangerous symptoms produced by cocaine. In 1904, stovaine (hydrochloride of dimethylaminobenzol-pentanol), which had been discovered the previous year by the French chemist Fourneau, was substituted for the more toxic cocaine, and the method once more came into prominence. Since that time many surgeons who have tried the method have had imperfect analgesia or deaths from technical defects, and from the unwise selection of patients; and after a brief trial have abandoned spinal anæsthesia. The use of intradural anæsthesia has therefore been greatly retarded by the carelessness and ignorance of many who have attempted to use it, as well as by the prejudice of those who have had no experience with the method.

Attempts to make spinal anæsthesia the universal anæsthetic, as well as attempts to make it the anæsthetic of choice for patients who are otherwise bad surgical risks, have served to discredit this valuable procedure. It should never be employed unless one has the requisite technical skill, and has mastered its indications and its physiologic action.

PHYSIOLOGIC ACTION

The spinal cord occupies less than one-half of the anteroposterior and transverse diameters of the spinal canal, leaving a considerable space within the arachnoid filled with cerebrospinal fluid. A local anæsthetic introduced within this space comes in contact, not only with the cord, covered by the pia-arachnoid, but also with the motor and sensory nerve roots, and the sympathetic segments within the spinal canal, and falls or rises as its specific gravity is greater or less than that of the cerebrospinal fluid. The cerebrospinal fluid shows little variation in specific gravity in health or disease, from childhood to old age. In a study of over one hundred cerebrospinal fluids taken from patients at different ages and with a variety of diseases, we found the specific gravity to show little variation from 1.0055 (Fig. 26). As it is not practicable to prepare anæsthetic solutions having the exact specific gravity of cerebrospinal fluid, it is desirable to use solutions distinctly lighter or heavier than the cerebrospinal fluid, and to localize the influence of the drug by the position of the patient. As the anæsthetic solution comes in contact with the nerve roots, it arrests their power of conductivity so that sensory loss, motor paralysis, and sympathetic paralysis occur in the segments affected. The autonomic system is practically uninfluenced. Immediately after the injection the patient usually notices a sense of paræsthesia in the feet, followed in a very few seconds by a complete loss of sensation and almost complete loss of motion. The small muscles of the toes and the iliopsoas muscle group usually retain some power. As would be expected, the area of epicritic loss is wider and more complete than the area of protopathic loss. If the analgesia is not deep, the patient may feel the knife, although the incision is not painful. The motor paralysis and loss of muscle and deep pressure sense are secondary to the loss of sensation, and indicate the full intensity of the action of the drug. As the anterior nerve roots are less exposed, or are less sensitive to the action of the anæsthetic than the posterior roots, analgesia may be present without complete muscular relaxation, especially if a weak solution or a feebler drug like procaine (novocaine) be used.

With a sufficient dosage of an active drug, the patient is entirely oblivious of the passive movement or changed position of the affected part. For example, if, while he is under the analgesia, the legs are raised and placed in the lithotomy position, the patient retains the concept that they are still flat on the table.

From a full adult dose, the action begins a few seconds after the injection, reaches its intensity in fifteen or twenty minutes, and after sixty to ninety minutes gradually disappears; the total duration of the analgesia varies directly with the dosage, and inversely, within limits, with the dilution.

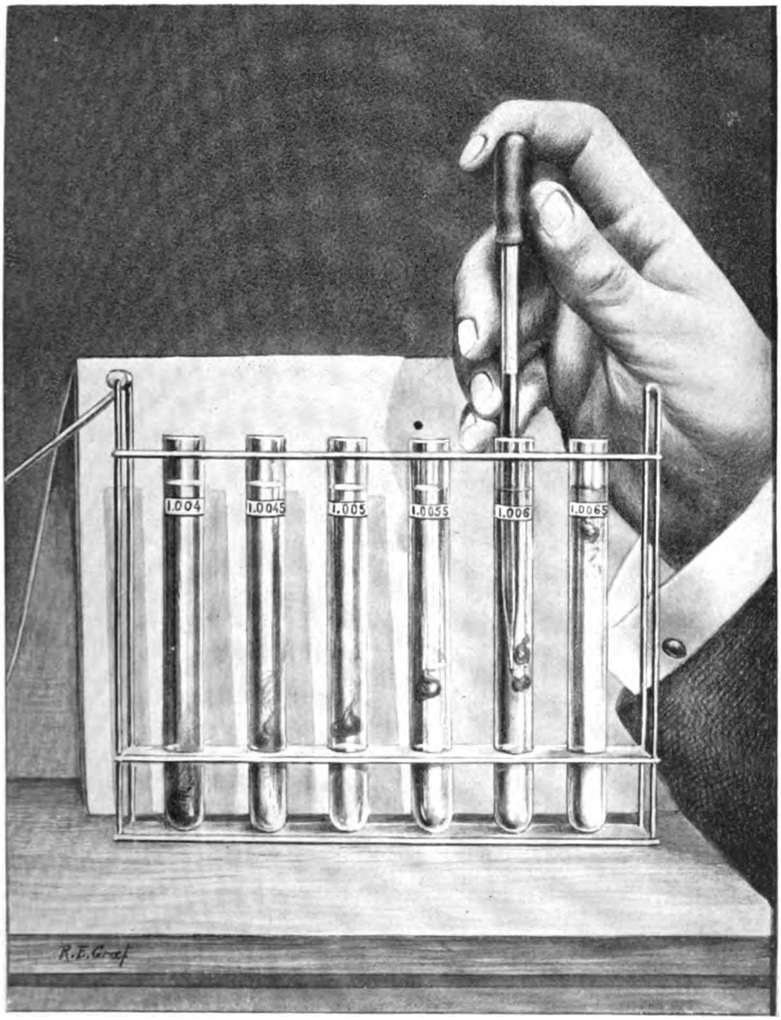

FIG. 26. APPARATUS FOR DETERMINING THE SPECIFIC GRAVITY OF CEREBROSPINAL FLUID (Babcock). The test tubes contain solutions of salt and water of known specific gravity. The cerebrospinal fluid is collected in minute tubes, the corks of which have been immersed in a weak alcoholic solution of methylene blue and dried, so as to color the cerebrospinal fluid. With a capillary pipette droplets of the colored fluid are expelled about the center of the fluid in each test tube, and the specific gravity is determined by the rise or fall of the droplets. In the illustration, as the droplet falls in a solution having a specific gravity of 1.005 and rises in a solution having a specific gravity of 1.006, the specific gravity of this cerebrospinal fluid lies between these two points.

Abdomen. Under spinal anæsthesia the abdominal walls become relaxed, and the abdomen more scaphoid. Abdominal breathing is largely abolished. The anal sphincters relax and the gaseous and liquid contents of the large intestine often escape. The intestinal tube contracts and shows active peristalsis. Except in the mechanical form ileus is usually promptly relieved by the injection. Even in mechanical obstruction of the intestine, the bowels may move and the condition be relieved while the surgeon is preparing to incise the abdomen. The influence on the intestinal tract may be explained largely by the release from intestinal inhibition. The vasomotor sympathetic nerves, the source of intestinal inhibition, are blocked, and the stimulating autonomic influence from the vagi and the motor stimulus from the ganglia of Auerbach are left unopposed.

Operative manipulations within the abdomen are greatly facilitated by the relaxed parietes and contracted intestine, and the expulsion of gas and fæcal matter before the patient leaves the operating table is especially helpful in intestinal obstruction. The stomach in some degree shares the peristaltic stimulation. If the upper dorsal segments are involved, nausea is often noticed, due probably to cerebral anæmia. The patient may be unable to vomit with the head raised, from paralysis of the abdominal walls. With the head and shoulders lowered, vomitus may escape as from an inverted bottle. If present, the nausea is usually very transient. It may also result from mental impressions. Secondary nausea or secondary paresis of the intestines from spinal anæsthesia we have not observed.

Genito-urinary tract. Under spinal anæsthesia the urinary excretion is distinctly diminished as a result of the lowered blood pressure. The ureters show periodic peristaltic waves that may be increased in frequency by mechanical stimulation.

Incontinence of urine is not produced by spinal anæsthesia. A slight or moderate degree of priapism is only occasionally observed, evidence that a marked influence on the lumbar cord is inconstant. Contrary to other observers, we have found no urinary evidence of renal irritation after spinal anæsthesia, and we do not believe that there is a shower of albumen or casts from the anæsthetic. Retention of urine following rectal, urethral, and other pelvic operations, occurs after spinal anæsthesia as it does after local anæsthesia and ether. It is a local reflex and probably has no relation to the intradural injection.

Circulation. Spinal anæsthesia is characterized by a fall in the blood pressure and a slowing of the pulse that are proportionate to the height and intensity of the anæsthesia. With involvement of the upper dorsal nerve roots, the pulse may drop to forty or thirty and the blood pressure to zero at the wrists, while an involvement of only the lower spinal segments may produce only a slight reduction in the pulse rate and blood pressure. The action on the circulation begins soon after the appearance of motor paralysis, reaches its acme in about fifteen or twenty minutes, lasts twenty to thirty minutes, and gradually passes off. The influence on the circulation may be explained by the following factors:

1. The pressor influences from the cord are interrupted and there is a vasomotor paralysis from action on the rami communicantes in the involved spinal segments.
2. The limitation of respiratory movements reduces the normal aspirating influence on the venæ cavæ, the right auricle fills slowly, and therefore the other cavities of the heart fill slowly.
3. The inhibitory influence of the vagi on the heart continues and is largely unopposed.

4. The most powerful normal stimulus to a vigorous heart action, the *vis a fronte,* is largely lost with the fall in blood pressure.

A blood pressure of zero at the wrists may be harmless if the respirations are well maintained. The hypotonus, however, favors cardiac arrest in certain forms of myocardial disease, as well as in thoracotomy and other operations causing sudden changes in the intrathoracic tension. The depression of the heart varies directly with the height of the motor paralysis, being greatest in high spinal anæsthesia. In aneurism, threatened decompensation of valvular disease, in the excessive tension of eclampsia, in labor, nephritis, and advanced arteriosclerosis the vaso-relaxation of spinal anæsthesia may be protective. Hæmorrhage from divided vessels and from the open uterine sinuses is greatly reduced under spinal anæsthesia, while there is no increased tendency to secondary or reactionary hæmorrhage. No other anæsthetic produces such a complete vasomotor relaxation, and for this reason spinal anæsthesia should be used with care or avoided in conditions of marked hypotension, while indicated in forms of hypertension. During severe shock, spinal anæsthesia, unless guarded by methods to be later described, should not be employed. It accentuates pre-existing shock, although it prevents to a remarkable degree the production of shock by the operative measures carried out under its influence. The best antidote for the fall of blood pressure is the intravenous injection of epinephrin.

Respiration. The respiratory movements diminish in amplitude according to the extent of paralysis of the respiratory muscles. With paralysis of the lower dorsal segments, the respirations become diaphragmatic in type, but are without the co-ordinate movements of the abdominal wall. As the muscles of the thoracic walls relax, the patient complains of a sense of weight or oppression on the chest. The skin, although pale, is usually dry and of fair color. If, however, the third, fourth, and fifth cervical segments supplying the phrenic nerves be influenced, although the patient may continue to make ineffectual respiratory movements with the accessory respiratory muscles of the neck, asphyxia rapidly develops and the patient will die unless efficient efforts at artificial respiration be instituted. If a solution of stovaine be applied to the floor of the fourth ventricle of a dog, the respirations are almost instantly arrested, but the animal may eventually recover, provided artificial respiration be continued until the centers emerge from the influence of the drug. A similar condition occurs in the human being in anæsthesia of the cervical segments, and one should not hesitate to continue artificial respiration for forty minutes or even longer. The respirations under spinal anæsthesia are usually slow and rather shallow; their small amplitude is favorable to the performance of abdominal operations. Cyanosis, as in other forms of anæsthesia, is always ominous. Respiratory movements are best gauged by a wisp of cotton fastened to the tip of the patient's nose, and this is the best indicator of the efficiency of artificial respiratory measures. Contrary to Jonnesco, the addition of strychnine to the anæsthetic solution does not prevent respiratory depression in spinal anæsthesia. From such a mixture we have observed strychnine convulsions in the upper part of the body, with motor paralysis and relaxation below in the area of the spinal anæsthesia.

Uterus. During labor, uterine contractions continue under the anæsthetic, but being without the normal aid of the voluntary expulsive forces, they are, as a rule, inefficient even when supplemented by the associated relaxation of the pelvic outlet. The blood pressure in the uterine sinuses is greatly reduced. Hæmorrhage during delivery or during curettement for miscarriage is distinctly less than that seen under chloroform or ether anæsthesia. When emptied, the uterus contracts promptly, and secondary hæmorrhage after delivery is unusual.

Skin. Except with the relaxation of high spinal anæsthesia the surface of the body is pale, or of normal color, and dry. The suffusion of the skin, drenching sweats, and heat radiation of ether are absent.

Local and general toxic action. The local anæsthetics, especially stovaine, are protoplasmic poisons. This is especially shown by their action on the cornea when introduced into the conjunctival sac. When a strong solution of stovaine is injected into poorly vascularized tissue, as in the prepuce, local necrosis follows. Injected into the spinal canal of a dog or other animal where there is very little dilution or diffusion of cerebrospinal fluid, the drug produces degenerative changes in the cord. One cannot, however, properly compare the action of a solution of stovaine in the spinal canal of a dog containing but 7 ccm. of fluid, with its action in the canal of a man containing 180 ccm. of cerebrospinal fluid. In dogs, the cord is often damaged and permanent paraplegia follows; in man, evidences of organic change in the cord following anæsthesia are almost unknown. A number of our patients have had three or more injections of stovaine, one has had nine, another twelve, without any evidence of degeneration. Some of these injections date back fifteen years, so it is evident that there is little danger of later degenerative change in the cord from the method. The direct injection of the anæsthetic solution into the substance of the spinal cord or one of the nerve roots may be followed by degenerative changes. In a case in which we made the injection into a nerve root, there followed a very violent sciatica with motor paralysis that very slowly improved. It has been thought that by absorption the stovaine used in spinal anæsthesia has a toxic action on the parenchymatous organs, but we doubt if the small quantity used, six centigrams, has an effect marked enough for practical consideration. In contrasting some thousands of patients after spinal anæsthesia with those having taken ether, one is impressed by the absence of postanæsthetic toxic symptoms after the intradural injections. Apart from the occasional meningeal symptoms, it is difficult to find any postoperative symptoms attributable to the spinal anæsthetic.

It is evident that spinal anæsthesia has a different physiologic action from that of any other anæsthetic. It is of chief value when its application is based on its peculiar physiologic action and when it is used in certain of the conditions that render the employment of other anæsthetics dangerous.

SELECTION OF PATIENTS FOR SPINAL ANÆSTHESIA

For upper abdominal lesions requiring operation, we consider spinal anæsthesia to have additional risk. Especially is this true with elderly obese patients with biliary disease, and fatty myocardium. The emaciated patient, if not in the stage of profound exhaustion, we consider a much safer subject. Therefore, we select local anæsthesia for an elderly fleshy woman in poor condition from purulent cholecystitis or hæmorrhagic pancreatitis, and spinal anæsthesia for an emaciated old man with carcinoma of the stomach who has evidence of some reserve power. We have used spinal anæsthesia for nearly all splenectomies, but of course the risk is increased by the high segment anæsthesia required.

For most intra-abdominal infections lying below the upper abdomen, spinal analgesia is especially valuable. In acute appendicitis with or without peritonitis; in acute forms of intestinal obstruction in which the patient is in fair general condition; or for intra-abdominal injury not associated with severe shock the complete relaxation of the abdominal wall and the facility of the exploration of the abdomen give spinal anæsthesia advantages over any other anæsthetic of which we have knowledge. By no other method can the operation be performed through such a small incision, with such rapidity, with so little exposure or intra-abdominal manipulation, with so little added toxæmia, with so little tendency for the intestines to protrude, and with such ease as to the suture of the wound. These advantages, of course, are lost when the operation consumes over one or one and one-half hours. Nearly all forms of herniorrhaphy are very conveniently performed under spinal anæsthesia, as are operations upon the lower urinary tract, particularly prostatectomies. The method lends itself to nearly all forms of gynæcologic surgery, except that in case there is a large fibroid of the uterus or other large tumor that presses upon the diaphragm and embarrasses respiration, or is associated with myocardial degeneration, the method has a distinct risk. In four cases in which ether was followed by collapse upon the table so that the operation could not be performed, spinal anæsthesia was later used without untoward symptoms; but on the other hand the only fatality we have seen from spinal anæsthesia where the patient was in fairly good condition was in an obese middle-aged colored woman with a very large fibroid tumor of the uterus. This patient developed respiratory and cardiac failure during the operation, and owing to delay in introducing adrenalized saline into the vein, cardiac massage failed to be efficient until about twenty-five minutes after the cessation of heart action. This patient, while respiration and circulation were finally reestablished by the aid of artificial respiration, did not regain consciousness, and died about two days later.

While we usually employ spinal anæsthesia for intra-abdominal hæmorrhage associated with marked shock, we consider it unsafe to do so without first tying a needle into a convenient vein so that, if necessary, transfusion with adrenalized saline may be started without delay. By this expedient, for example, we were able to carry a patient, pulseless and apparently moribund from rupture of the pregnant uterus, through a Porro operation with a final recovery. As operations upon the rectum and anus require only a very low spinal anæsthesia, and as the relaxation of the anal sphincter facilitates the work of the surgeon, it may be recommended in these cases.

Intradural anæsthesia we have routinely used in the so-called tragic types of ectopic pregnancy. In these cases facilities for an instant intravenous injection should always be at hand.

In obstetric surgery spinal anæsthesia is relatively safe, and is efficient if the operation can be completed within the time limits of the analgesia. The uterine contractions continue, the lower portion of the birth canal is entirely relaxed, but all voluntary expulsion efforts are abolished. The delivery of the child must be manual or instrumental. Hæmorrhage during delivery or during a curettage is diminished by spinal anæsthesia, the uterus usually firmly contracts after delivery, and there is no increased danger of postpartum hæmorrhage. Of course, the anæsthetic has no untoward influence on the child. For Cæsarian section spinal anæsthesia is efficient, reducing the operative hæmorrhage. J. P. Marsh, of Troy, N. Y., reports six cases of Cæsarian section under spinal anæsthesia for eclampsia with no maternal deaths. On account of the high blood pressure the intradural injection is especially safe in eclampsia. All patients with serious valvular heart disease or fairly advanced forms of pulmonary tuberculosis should be spared the strain of labor by an artificial delivery under spinal or an equally innocuous anæsthetic.

In operations on the kidneys or uterus, except in the obese patient with a poor myocardium, we prefer lumbar anæsthesia. Operations on the spine, in patients in good condition, are conveniently carried out under spinal anæsthesia. The analgesia may be prolonged indefinitely by dropping a small quantity of the stovaine solution on the exposed nerve roots whenever the patient shows evidence of returning sensation. If the respirations are embarrassed, or hypotension present, spinal anæsthesia should be avoided or used with great care. The position usually used for laminectomy may seriously interfere with respiration.

For minor operations such as aspiration, circumcision, or ingrown toenail, we feel that such a potentially dangerous analgesia should not be employed. For most of the more serious operations upon the leg spinal anæsthesia has advantages.

Except in extreme exhaustion or when in a dying condition, infants are good subjects for spinal analgesia. It is desirable to use a somewhat smaller and shorter needle, and the child should be firmly held during the introduction. Usually there is less excitation from the needle puncture than from the inhalation of ether, and the infant quickly forgets the pain of the needle and frequently sleeps during the operation. We have repeatedly operated on infants from 24 hours to several weeks old, for spina bifida or other congenital defects, under spinal anæsthesia. It is especially valuable for children with peritonitis from appendicitis or other cause. We know of but one instance of the death of a baby under spinal anæsthesia, and in this case we gave high spinal anæsthesia for a pulmonary abscess. During the progress of the operation while the lobes of the lung were being separated the child suddenly died. The infant had an advanced miliary tuberculosis, and was in such bad condition that for several weeks preceding the operation death had been expected almost daily. If used in adolescence spinal anæsthesia is also relatively safe. In military practice for soldiers not exhausted by shock or disease it is very satisfactory. In middle or advanced life the danger from spinal anæsthesia distinctly increases, from the increasing tendency to myocardial disease. In old age, in patients with fair myocardia who are not overly obese, intradural anæsthesia is relatively safe and efficient.

Of the general diseases which contra-indicate spinal anæsthesia, myocardial degeneration is perhaps the most important. Obese, middle-aged, or elderly patients should therefore be carefully studied before spinal anæsthesia is administered. In valvular disease of the heart, unless the compensation is very seriously broken, it may be used. Indeed, we have not hesitated to use it in the presence of ascites or other evidence of moderate decompensation. It is particularly safe in forms of heart disease associated with high arterial tension. In case the heart or lungs are seriously embarrassed by an effusion within the pericardium or pleura, it should be used with caution or avoided. Pulmonary tuberculosis, except in the very massive, advanced forms, does not contra-indicate spinal anæsthesia, which has the advantage of not acting unfavorably upon the lungs. In acute respiratory infection it is also often the method of choice. In renal disease, except in those cases associated with advanced forms of myocardial degeneration or extreme debility or exhaustion, it may be used with great advantage. It is perhaps the safest anæsthetic in diabetes. While it is efficient despite the presence of tabes dorsalis, it should be remembered that the later progress of the disease may be laid to the injection. Neurotic patients have a tendency to ascribe any later pain that they may have, particularly about the back or head or legs, to the intradural injection, and it is to be recalled that there is a large percentage of postoperative backaches in the clientele of most gynæcologists.

TECHNIQUE

As has been indicated, the nerve segments influenced in spinal anæsthesia vary according to the interspace selected for the injection, the posture of the patient, the specific gravity and strength of the solution employed, and the rapidity of the injection. As a rule, the higher the point of injection, the greater the effect produced.

High spinal anæsthesia refers to analgesia of segments above the level of the diaphragm. One may produce an effect on the higher spinal segments after withdrawing from 5 to 20 ccm. of cerebrospinal fluid, by introducing through a lower interspace an equally large bulk of the dilute anæsthetic solution. The cerebrospinal fluid withdrawn may be used to dissolve the drug. A second method is to introduce a solution made heavy by the addition of glucose, dextrin, milk-sugar, or other substance, and by a postural manipulation to confine the anæsthetic to the vicinity of the nerve roots that it is desired to influence. Thus, Barker injects a 5 per cent solution of stovaine in a 5 per cent solution of glucose with the patient on the side, the shoulders and hips being slightly elevated (Fig. 27). The patient is then cautiously rolled on the back, the eleva-

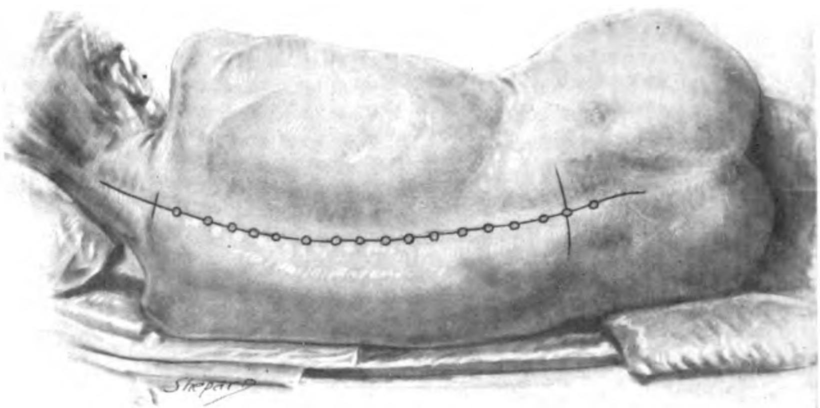

FIG. 27. LATERAL POSITION FOR PUNCTURE FOR HIGH ANALGESIA.

tion of the shoulders and hips being maintained by suitable pads or boards (Fig. 28). The most dependent nerve roots in the lower dorsal region are thus chiefly bathed by the anæsthetic. A third method we have employed is to inject a solution lighter than cerebrospinal fluid (solution A), with the patient in the sitting posture. The solution ascends with an approximate speed of 10 cm. a minute, and at the end of the calculated time (one to three minutes), the patient's shoulders are quickly lowered below the level of the hips. Injections through the upper interspaces have been advocated by Jonnesco. By making the injection through the seventh cervical interspace one can produce analgesia in the area supplied by the cranial and cervical nerves, and operate upon the head, neck or upper thorax. For the high injection it is necessary to reduce the dosage about one-half and as a result the duration of the analgesia is only about ten or twenty minutes; during this time, despite the small dose, the patients usually are in shock and not infrequently develop respiratory or cardiac failure. Until a drug is found that will act upon the sensory nerve roots, but not on the motor nerve roots, high spinal anæsthesia is too dangerous ever to be employed.

The method we prefer for subarachnoid anæsthesia is to use a solution distinctly lighter than that of the cerebrospinal fluid. Although the cerebrospinal fluid has a relatively constant specific gravity ranging almost invariably between 1.0055 and 1.0065, it is impracticable to use an anæs-

FIG. 28. PATIENT ROLLED OVER ON BACK AFTER THE INJECTION.

thetic solution that will so closely approximate its specific gravity as to remain at one level after its introduction into the spinal canal. The slightest variation in the specific gravity will cause the solution to rise or fall; so it is desirable to use a solution known to be either heavier or lighter than that of the cerebrospinal fluid. The light solution lends itself to the use of the Trendelenburg position, or to lowering the head when marked circulatory depression occurs.

After the injection the patient is instantly laid upon the operating table with the shoulders about two inches lower than the hips. Great care is taken that the shoulders are not raised for one hour after the injection. After the use of the heavy solution the raising of the hips for the application of a bandage has been followed by the sudden cessation of respiration and circulation; and elevation of the head and shoulders after the injection of the light solution has been followed by syncope; so great care should be taken to place the patient in the proper position immediately after the injection, and to maintain this position until the effects of the drug have worn off. The patient should not be shaken or moved to any degree after the injection. In a recorded case a debilitated patient was given the injection, wheeled to the elevator, and taken up three stories, when he collapsed and died as he was being taken from the elevator to the operating room. The injection should be given in the operating theater, on the operating table, and the patient should be as carefully watched as though he were under chloroform. It is obvious that a patient who cannot safely be placed in the position required by spinal anæsthesia, should not be given the injection. Patients who cannot breathe with the head low should not be operated upon under spinal anæsthesia.

The following solutions are satisfactory for spinal anæsthesia:

Light solutions; specific gravity, 0.992.		
A.	Stovaine	0.08 gm.
	Lactic acid	0.04 ccm.
	Absolute alcohol	0.2 ccm.
	Distilled water	1.8 ccm.
B.	Tropacocaine	0.1 gm.
	Absolute alcohol	0.2 ccm.
	Distilled water	1.8 ccm.
C.	Procaine (novocaine)	0.16 gm.
	Absolute alcohol	0.2 ccm.
	Distilled water	1.8 ccm.
Heavy solution; specific gravity, 1.020.		
D.	Stovaine	0.08 gm.
	Lactic acid	0.04 ccm.
	Milk-sugar	0.10 gm.
	Distilled water to make	2.0 ccm.

These solutions are conveniently kept in ampoules, each containing 2 ccm. of solution. They should be prepared under aseptic precautions and sterilized by the intermittent method and at a temperature of 65° C. (149° F.). The dose of each solution for the adult is 1-1.5 ccm.; the larger dose is employed only for robust adults. Of these solutions that of stovaine is the most powerful anæsthetic and motor paralyzant, the most toxic, most actively hæmolytic, and the strongest protoplasmic poison. If not acidulated it is precipitated by the alkaline cerebrospinal fluid. It gives excellent anæsthesia and for some years we have only used solution "A." Tropacocaine is slightly less active as an anæsthetic, and the solutions we have obtained have not been so uniform as the solution of stovaine. Ampoules supplied by various firms at times show variation in analgesic power and in toxic action due to deviation from the printed formula, to imperfect sterility, to by-products not eliminated in the manufacture, or produced as a result of the decomposing effects of heat. Bacteria have been found in ampoules supplied by a German firm, and two consignments we received from England containing dextrin showed a heavy fungous growth. Novocaine is much weaker than stovaine, but is not precipitated by cerebrospinal fluid, and even in a 10 per cent solution is not actively hæmolytic. The clinical efficiency and clinical toxicity of novocaine within the dura we estimate as about one-half that of stovaine. The loss of tactile and thermic sense is less under novocaine. Solution "D" is to be used in the rare instances in which it is desired to keep the head elevated during the operation. Solutions extemporized from powders or tablets should be abandoned from fear of infection. The only death from septic meningitis following the intradural injection, of which we have knowledge, occurred after the use of a commercial tablet.

Dosage. The dose for an adult of each of the solutions mentioned is 1 - 1.5 ccm. (15 - 24 minims, or 0.04 - 0.06 gm. stovaine), the larger amount being used only in the robust. Children will stand relatively large doses; thus, 0.015 gm. (1/4 grain) of stovaine may be given in the new-born; 0.03 gm. (1/2 grain) to a child of five years of average size and robustness; and 0.04 gm. (2/3 grain) to a child of ten.

Site of injection. It is best to make the injection approximately opposite the nerve roots supplying the field of operation. From the point of injection the anæsthetic effect diffuses upward and downward with diminishing intensity, and recedes after reaching its greatest amplitude, disappearing last from the nerve roots first influenced. The most complete and most prolonged analgesia, therefore, will be found in the nerve roots opposite the point of injection. For operations upon the upper abdomen the eleventh or twelfth dorsal interspace should be selected; for lower abdominal operations the first dorsal interspace; for operations upon the thigh or inguinal region the first or second lumbar interspace; for operations upon the legs the second lumbar interspace; while for operations upon the external genitals, perineum, and anus, the third or fourth lumbar interspace is to be preferred. The higher injections, from their intense influence upon the respiration and upon blood pressure, are much more dangerous than the lower and should not be generally employed.

Apparatus. The success of spinal anæsthesia depends in no little degree upon the selection of the syringe and needle. A carefully ground glass syringe of the Luer type of 2 ccm. capacity, graduated to 0.1 ccm.,

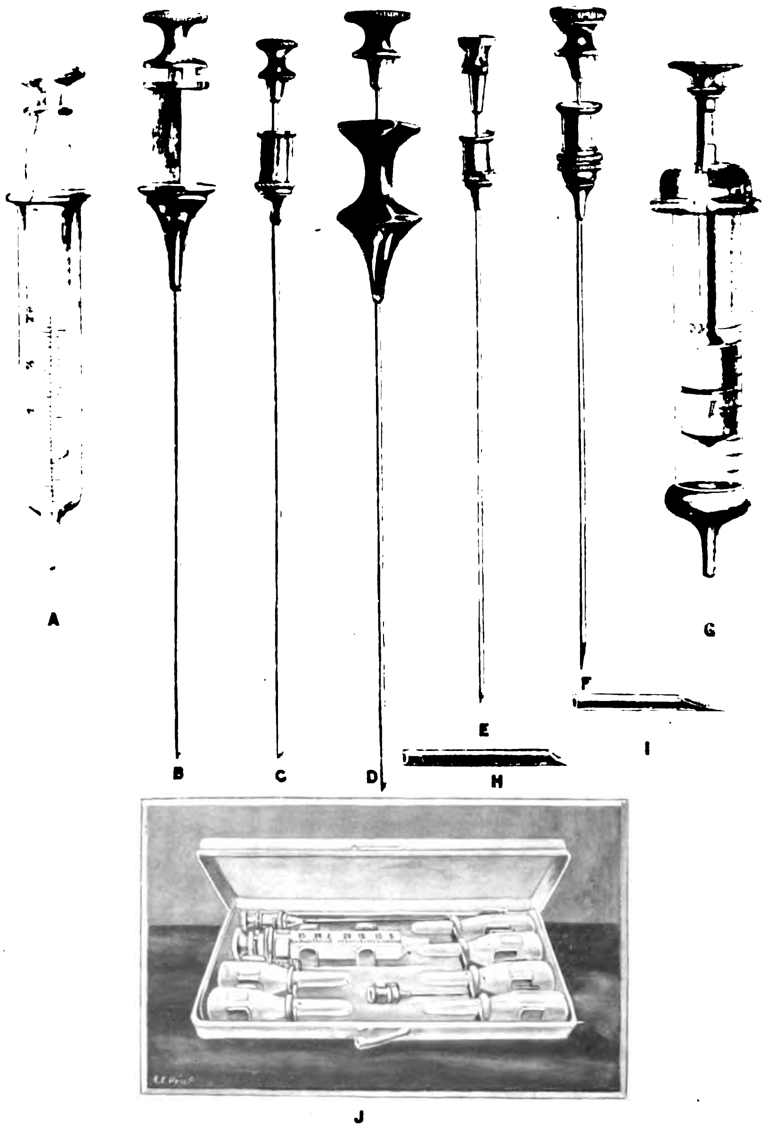

FIG. 29. (See legend on opposite page.)

is preferred (Fig 29). This syringe is light and, if properly made, the piston fits loosely enough to be forced out by the pressure of the intradural fluid, important evidence that the needle has properly entered the subarachnoid space. The Record syringe is too heavy, and has a piston moving only under too great a pressure. For delicacy of manipulation the needle should likewise be small and light, preferably of iridio-platinum, 7 cm. long and 1 - 1. 5 mm. in diameter. The point should be sharp, but very oblique and hollow ground, so that the length of the beveled portion is not over 2 mm. The needle should be provided with a well-fitted stylet or mandrin, that the needle point may not become clogged by tissue during the introduction; and the needle should fit the syringe accurately by a slip and not a screw joint. Needles made of the harder alloys of gold or nickel are practicable, but they lack the rigidity and the temper possessed by the platinum alloy. Steel needles have so frequently broken during or after the introduction that they should be avoided. If the needle is too large, secondary leakage of cerebrospinal fluid and of the anæsthetic, with imperfect anæsthesia and secondary headache, may occur; if the needle is too small it is more difficult to guide it correctly and to introduce the solution properly. A needle out of balance, from a large and heavy head, impairs the operator's ability to discern the different structures traversed by the needle point (Fig. 29).

Technique of injection. The syringe, needle, and stylet should be wrapped in clean gauze and boiled in distilled water, free from alkali, for fifteen minutes just before using. They should never be boiled with other instruments, as the addition of alkali or other contamination may decompose the anæsthetic drug or give rise to meningeal irritation. Without being removed from the container, or the hot solution, the apparatus should be brought to the operator just before the injection, and to limit the responsibility for any possible infection, only the operator should handle the syringe. The hot syringe not only ensures sterility but also serves to warm the anæsthetic solution to about the temperature of the body. The ampoule, which is not touched by the operator, is opened just before use and so held or placed that the operator may aseptically withdraw the solution into the syringe. The operator accurately

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FIG. 29. INSTRUMENTS FOR USE IN SPINAL ANÆSTHESIA. *a*, Glass Luer syringe, which is preferred to the Record syringe, *g*. *b, c, d, e, f*, Various spinal needles. The lighter and more delicate needle of iridio-platinum, *c*, is preferred to the heavier Bier needle, *b*, or needles out of balance by reason of heavy heads, as *d* or *f*. Needles with notched heads, *c*, frequently leak; *h*, is a proper, *i*, an improper needle point. *j*, Case containing spinal anæsthesia outfit including ampoules of stovaine, epinephrin, pituitrin, and of strychnine with caffein and sodium benzoate.

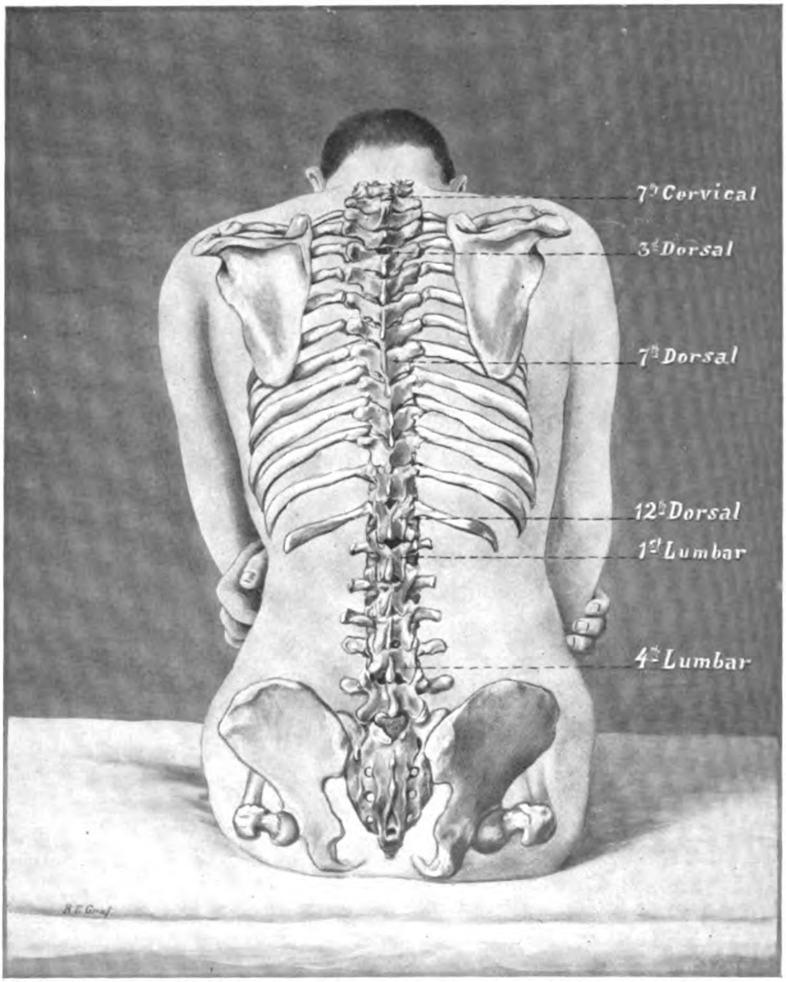

FIG. 30. LOCALIZATION OF THE SPINOUS INTERSPACES. The seventh cervical is marked by the projecting spine of the vertebra prominens. The third dorsal is opposite the spine of the scapula; the seventh dorsal opposite the angle of the scapula. The twelfth dorsal usually shows the most marked interspace depression. The first lumbar is opposite the tip of the twelfth rib, the fourth lumbar opposite the iliac crests.

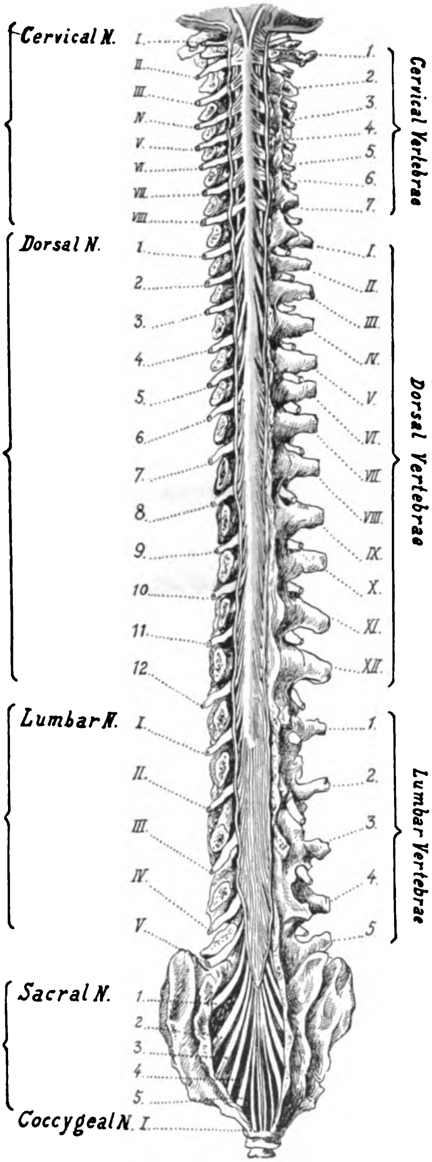

FIG. 31a. RELATION OF THE SPINAL NERVE ROOTS AND THE VERTEBRÆ.

measures the quantity of solution to be employed, expelling the excess and any air bubbles from the syringe. The interspace through which it is desired to inject is located by stretching a sterile towel across the iliac crests, giving the line of the fourth lumbar spine or interspace. Having

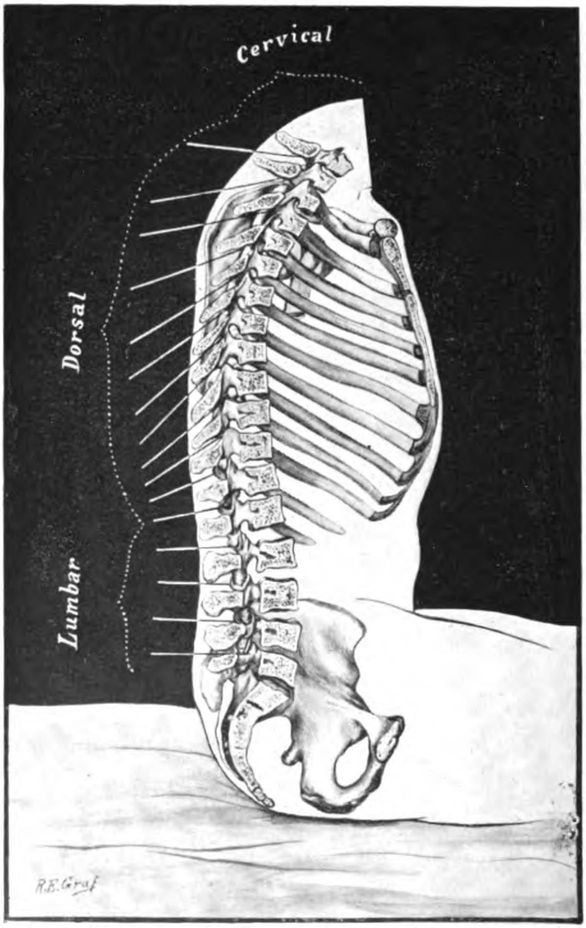

FIG. 31b. DIRECTION FOR INSERTING THE NEEDLE IN THE VARIOUS REIGIONS OF THE SPINE.

located the fourth lumbar spine the operator counts up to the interspace desired (Fig. 30). For a lumbar injection, the needle containing the stylet, should be inserted close to the midline at about the vertical center of the interspace at right angles to the body surface, and should be carried directly forward until it is felt in the grasp of the dense interspinous ligament. If only soft non-resistant tissue is encountered, the needle has probably deviated to the side, and should be withdrawn and re-introduced. Having entered the interspinous ligament the stylet is withdrawn and the needle cautiously pushed forward with short quick strokes a few millimeters at a time. A loss of resistance noticed as the needle point leaves the interspinous ligament and enters the loose areolar tissue outside the dura, warns the operator. A slight resistance and a snap, sometimes

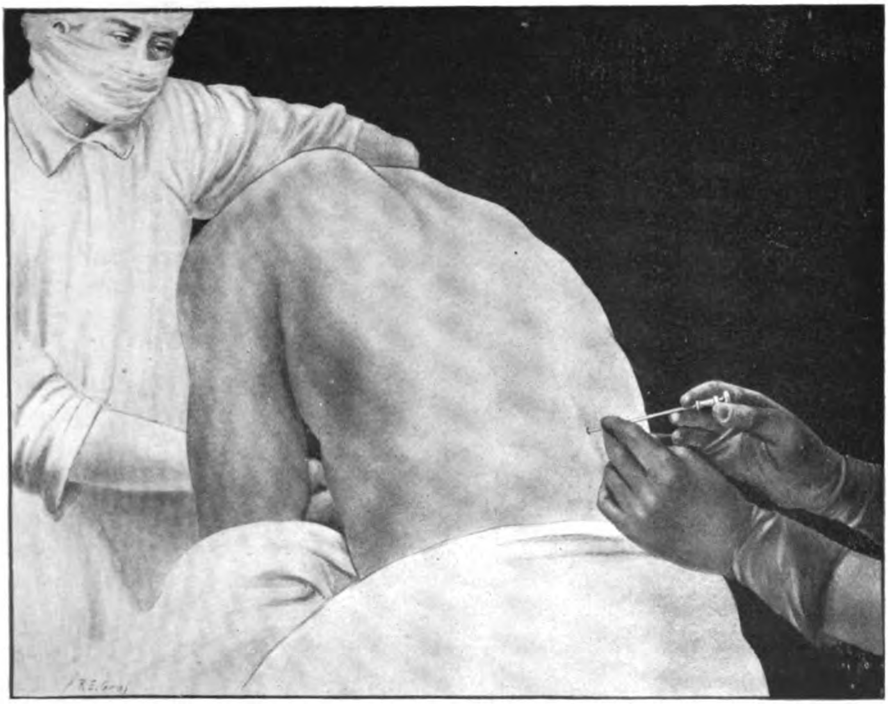

FIG. 32a. INTRODUCTION OF THE NEEDLE. The patient's back should be arched rather than tilted forward, the needle should be lightly grasped, being supported and guided by the left hand as it is introduced by the right.

audible, indicate that the tense dura has been punctured. The success of the introduction is shown by the free flow of the cerebrospinal fluid from the needle. With the penetration of the dura the needle is partially rotated to make sure that the point is entirely through the membrane, and if the cerebrospinal fluid does not flow freely, the needle is again cautiously rotated or slightly moved. At times it is necessary to re-introduce the stylet and cautiously aspirate, or to seek another interspace; the latter is the better plan where there is much difficulty. If the needle enters directly in the median line, a few drops of blood may flow from puncture of the median extradural vein (Fig. 33); this slight hæmorrhage usually is harmless, and the blood is usually quickly followed by cerebrospinal fluid. Carefully supporting the needle (Fig. 32a) and with as little loss of cerebrospinal fluid as possible, one immediately affixes the syringe

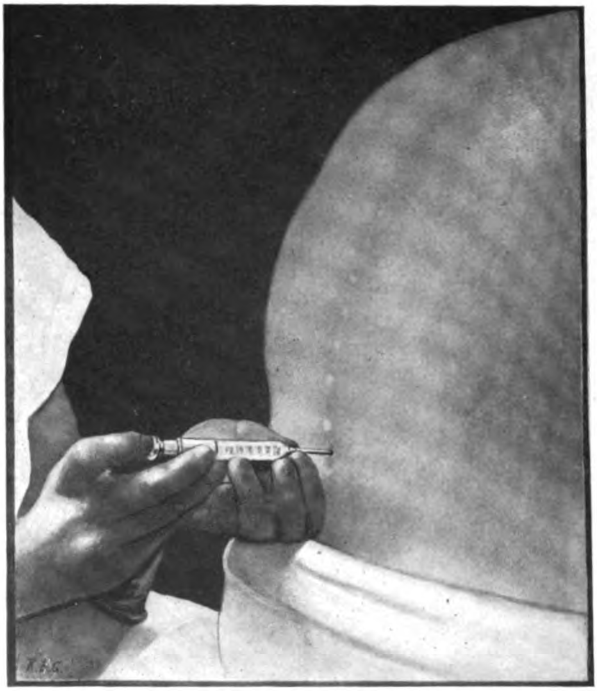

FIG. 32b. THE SPINAL INJECTION. The needle is carefully supported to prevent displacement during the injection, and the solution injected intermittently with repeated partial withdrawals of the piston to obtain sufficient admixture with the cerebrospinal fluid.

and withdraws the piston a short distance, permitting cerebrospinal fluid to mix with the anæsthetic solution, and proving that the needle point is in proper position. Unless the cerebrospinal fluid flows freely, the injection should not be given. To ensure thorough diffusion a part of the mixture is injected, a little more cerebrospinal fluid withdrawn into the syringe, and this process is repeated two or three times until the syringe is empty. Although these manipulations should be gentle and not too rapid, not over 15 seconds should be consumed in giving the injection.

The needle is now quickly withdrawn and the patient immediately placed in position upon the table. If the light solution has been used, the patient's shoulders are at once lowered at least two inches below the level of the hips; while if the heavy solution has been employed, the head and shoulders must be kept elevated. With a sharp needle the procedure causes little pain, and no local anæsthetic is required. The small needle puncture, apart from being covered by a sterile towel, requires no dressing or other protection.

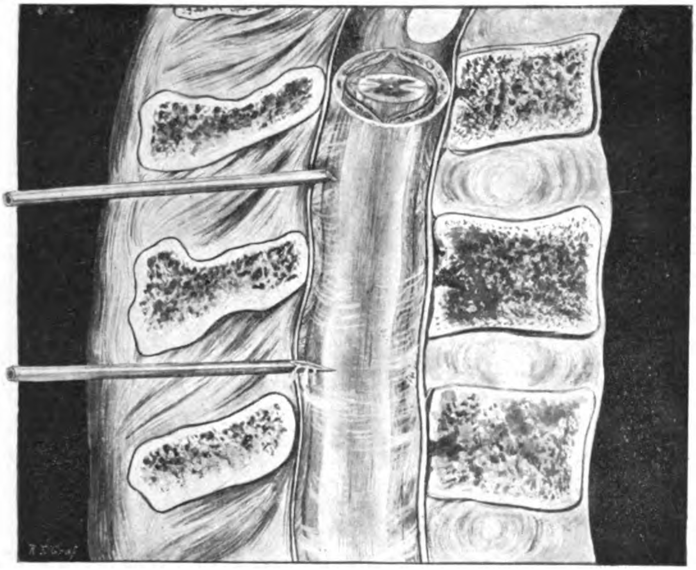

FIG. 32C. PROPER SHAPE (UPPER) AND IMPROPER SHAPE (LOWER) OF NEEDLES FOR USE IN SPINAL ANÆSTHESIA. The latter needle point endangers the cord and permits extradural leakage of the anæsthetic.

A final preparation of the operative field is now made, and the operation started without further delay. Analgesia is determined by watching the face while the skin is pinched, or by noticing the relaxation of the rectus abdominus, or the anal sphincter. In case of doubt the patient is asked to raise the leg from the table without bending the knee; this he should be unable to do. On account of its bad psychic influence, the patient should never be asked if he has pain. If at the end of six minutes no analgesia is present, one may repeat the injection, using an equally large dose of the drug and selecting the same, or perhaps better, an adjacent interspace.

Failure to obtain anæsthesia. In from 2 to 4 per cent of the patients, even with a skilled technique, no analgesia is found after the injection. This may be explained in one of the following ways:

1. Failure to enter the spinal canal. Very rarely, bony deformity, especially that following Pott's disease, prevents the introduction of the needle. An absolute bony impediment is very rare. In about ten thousand injections for spinal anæsthesia, we know of one case, a kyphotic dwarf from Pott's disease, in which repeated attempts to introduce the needle failed. The inexperienced surgeon may, however, frequently have trouble through failure carefully to follow out the directions given. Usually the needle is not entered sufficiently close to the center of the interspace and is pointed up or down, or is bent or diverted in the introduction; or the patient is not held in a proper position. Occasionally the patient is rigid, or the laminæ overlap so that an adjacent interspace from the one selected has to be substituted.

2. Failure to enter the cavity of the arachnoid is determined, first, by the absence of the sensation imparted as the needle point penetrates the dura, and second, by the failure to obtain a free flow of cerebrospinal fluid from the needle. A partial penetration of the dura, due to failure to rotate the needle, or the presence of an extradural œdema or leakage of cerebrospinal fluid after a previous injection, may cause the operator to obtain free fluid from without the dura and to think that he has made the injection properly. The small amount of solution used for spinal anæsthesia will not give analgesia when injected without the dura, and for this reason the injection should never be given unless cerebrospinal fluid is running freely from the needle.

3. A needle too large or too small will not give as good results as a needle 1 – 1.5 mm. in diameter. The large needle permits leakage of cerebrospinal fluid from the dura with possible loss of some of the anæsthetic, while with a small needle it is more difficult to obtain a satisfactory admixture with the cerebrospinal fluid.

4. Too rapid an injection without sufficient diffusion may explain an imperfect anæsthesia.

5. Insufficient dosage, or, much more frequently, the introduction of the needle through too low or too high an interspace, is often responsible for failure to obtain analgesia in the segments of the operative field.

6. A tumor or an inflammatory mass filling the spinal canal, preventing the entrance of the needle into free spinal fluid and the diffusion of the anæsthetic to the desired nerve roots, is an exceedingly rare cause of lack of analgesia.

7. Deflecting membranes or bands within the dura preventing uni-

form diffusion of the drug may be responsible for poor analgesia. In a small percentage of the cases we have found it necessary to give two or three injections before obtaining analgesia.

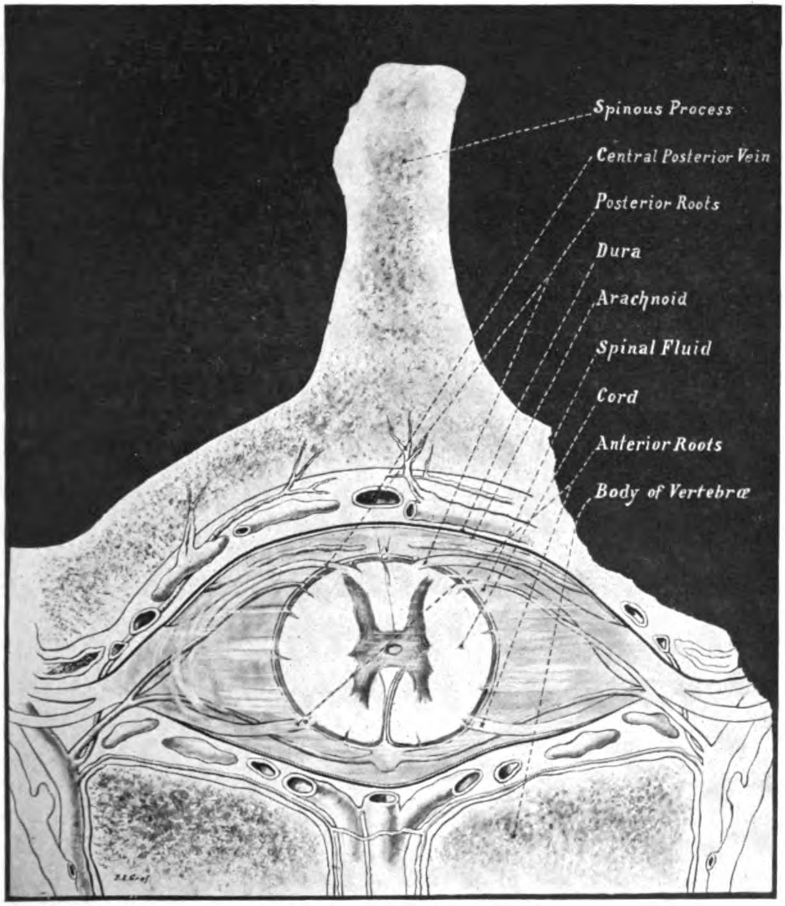

FIG. 33. TRANSVERSE SECTION OF SPINAL CANAL. Showing structures traversed, including central posterior vein, which lies in the midline, and is frequently punctured.

Danger signals in spinal anæsthesia. 1. Gulping and nausea precede a fall in blood pressure and are due to cerebral anæmia. Lower the head and chest. Given one ampoule of pituitrin hypodermically.

2. Cyanosis and a slow shallow respiration are ominous. Administer subcutaneously strychnine, gr. 1/15, caffeine, grs. 5. Use arti-

ficial respiration by rhythmic compression of lower thorax, or forced insufflation. If this fails prepare for tracheotomy and give epinephrin intravenously until the condition improves.

3. Regurgitant vomiting may drown the patient. Turn the head to one side; prepare for tracheotomy. In cases of intestinal obstruction, with regurgitant or stercoraceous vomiting, operation should be preceded by careful gastric lavage.

4. Cessation of heart action is always fatal if it persists over seven minutes. It may be anticipated by (a) pituitrin, subcutaneously or intravenously immediately before operation; (b) epinephrin, 10 minims of 1 : 1000 solution. Prepare the arm for transfusion, or if the patient is in very bad condition, tie a needle in the median basilic vein under local anæsthetic before the spinal injection is given. Connect the needle with a tube and funnel filled with physiologic salt solution, or Ringer's solution. Drop adrenalin into the funnel and permit the solution to enter the vein from time to time as may be required to maintain a slight pulse at wrist. When the heart stops rhythmically percuss or compress the chest in the region of the pericardium, and increase the adrenalin transfusion; or pass the left hand through an abdominal incision under the diaphragm, place the right hand on the precordia and compress the heart 40-60 times per minute with a slow complete compression followed by a quick release until the muscle responds. This should not fail if one's technique is good and adrenalin enters the coronary arteries. The heart may be massaged by a finger introduced through a stab wound four centimeters to the left of the sternal border in the fourth interspace. The adrenalin is effective only when it enters the coronaries; hence, if the heart has stopped, the cardiac massage must be used to enable the adrenalin solution to pass through the heart.

The patient's life often depends upon the promptness and intelligence of the observer. Anticipate danger by giving the proper treatment early, and by being ready for eventualities. For weak or obese patients use a cotton indicator on the nose, and watch the pulse constantly. Hypodermics are of use only when given before the circulation fails. Have an arm prepared for transfusion and all instruments close at hand for the hypotonic patient. Be sure the transfusion needle is not clogged, and that it is in the vein and not in the tissues, that the rubber tubing is not brittle, and that all connections are airtight. Do not hesitate to expose the vein freely in an emergency. Use sufficient but not too much epinephrin; in one patient 2 minims of the diluted 1 :1000 solution may be excessive, in another 100 minims hardly sufficient. Stop the injection as soon as the pulse returns to the wrist in order to prevent undue circulatory strain, and resume the transfusion as soon as the pulse fails.

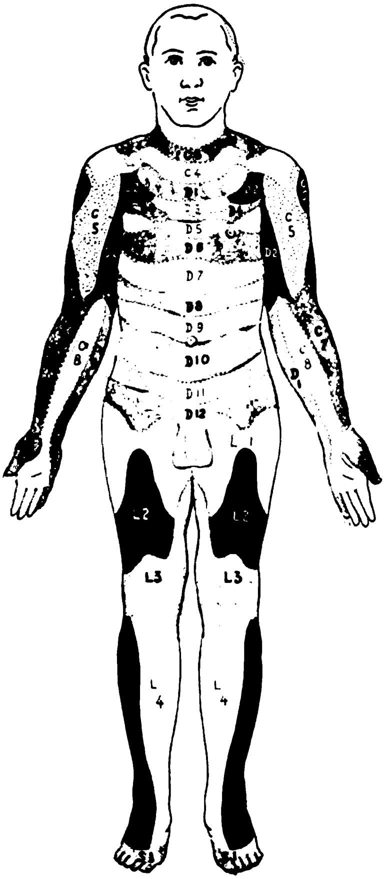

Fig. 34a.

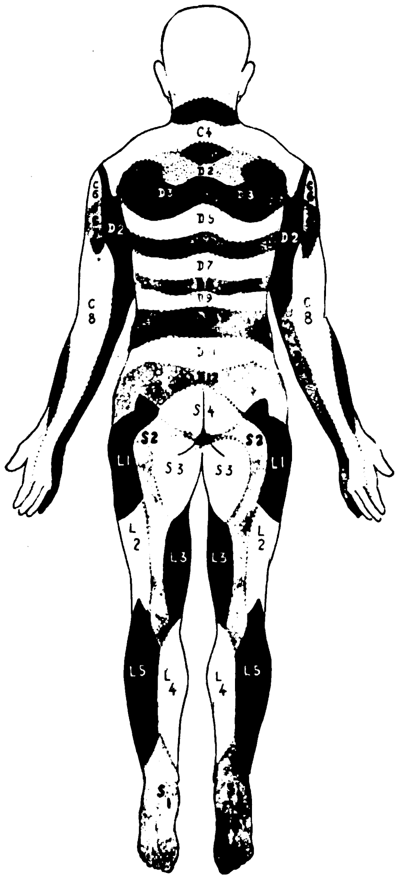

Fig. 34b.

FIG 34a. SPINAL SEGMENTS, ANTERIOR VIEW. Spinal anæsthesia is a nerve root anæsthesia in which sensory and motor conduction are abolished in the segments affected. Incomplete anæsthesia usually shows a segmental distribution, and is a result of technical error.

FIG. 34b. SPINAL SEGMENTS, POSTERIOR VIEW.

CARE OF PATIENTS AFTER OPERATION

The most frequent postanæsthetic symptom is headache, chiefly noticed in the occipital region and vertex, and increased by elevating the head. When intense this is associated with some rigidity of the posterior muscles of the neck, and backache. It may arise from leakage of the cerebrospinal fluid as after a simple lumbar puncture, especially when a large needle has been employed, or be due to some irritating substance in the anæsthetic solution. The average duration is from three to eight days. The cephalgia may be treated by the usual coal tar sedatives, with or without caffeine, and by lowering the head and shoulders. Headache should be less common after spinal anæsthesia than after ether, and if more than 10 per cent of the patients have this symptom the solution used should be discarded, and the technique of administration carefully reviewed. Secondary lumbar puncture in these cases shows a clear fluid, usually with low cell count, and as a rule does not relieve the symptom, which gradually subsides spontaneously.

Paralysis of the external rectus may occur after the intradural injection of any local anæsthetic; usually it is unilateral, although at times bilateral, and is probably an infection due to the presence of bacteria in the dural sac. After an incubation period of about seven days, during which time there is usually intense headache and backache, the patient suddenly develops a strabismus which, after lasting from a few days to six weeks, usually spontaneously disappears. The condition is probably due to an effect upon the nucleus in the fourth ventricle. The uniform incubation period, the associated evidence of meningeal irritation, the limited course, and the rarity of the condition after the injection of alcoholized solutions indicate the bacterial character of the paralysis. In our first three thousand injections, in which various drugs were used, there were six cases of abducens palsy. During this time imported solutions were largely employed, some of which were of questionable sterility. With the adoption of pasteurized and alcoholized solutions we have seen no additional case in about seven thousand injections.

Delayed secondary symptoms after spinal injection should immediately be studied by a competent neurologist, as an apprehensive patient or his friends or an unwise medical consultant may ascribe any postoperative symptom to the unusual anæsthetic used, and it is very important positively to determine the truth in every case. Almost invariably later secondary symptoms ascribed to spinal anæsthesia prove to be independent lesions or the result of hysteria or a neurosis.

Other conditions that have been reported from spinal anæsthesia, but that are so rare that they only require mention, are bulbar symptoms, such as cold sweats, vomiting, syncope, and labyrinthine disturbances with deafness. Renal and hepatic insufficiency have been ascribed to spinal anæsthesia, but have probably been the result of associated disease. Metastatic tuberculous meningitis has been ascribed to the injection. In one case several weeks after the resection of a tuberculous knee-joint the patient developed tuberculous meningitis. We considered this coincidental. In kyphoscoliosis and Pott's disease we have not hesitated to make the injection; it is important, however, that the needle should not pass through tuberculous areas.

General directions for the care of patients. As the safety of the patient, after the injection, rests largely with the assistants and nurses, it is wise to post directions like the following in the operating room:

1. For robust patients between 20 and 65 years of age, a hypodermic of 1/6 gr. of morphine and 1/100 gr. of hyoscin hydrobromide is to be given 75 minutes before operation, and, in certain cases, repeated 45 minutes before operation.

2. For septic, shocked, or asthenic patients, preliminary narcotism should not be employed. It should be avoided in children and the aged, while for robust nervous patients it may be repeated.

3. The back is prepared before the patient enters the operating room, by shaving, washing, drying, and painting with 2.5 per cent tincture of iodine.

4. Before a nervous patient enters the operating room, the eyes may be bandaged and cotton placed in the ears. Many patients have less fear if they have some knowledge of what is going on.

5. The patient is made to sit upon the side of the operating table, well back from the edge, with his elbows evenly at his sides, and the forearms crossed in front of the abdomen. The patient's back is again painted with tincture of iodine. The head is tilted forward until the chin touches the chest. An assistant stands on a low stool facing, and slightly to the left of the patient, whose hands he holds in his right hand while his left arm passes back of the patient's neck and his fist presses against the patient's epigastrium (Fig. 32a).

6. The spinal syringe, with the piston separated, and the needle containing the stylet are brought to the operating table in boiling water immediately before the injection is to be given. To reduce the chance of infection, no one but the gloved operator touches the syringe or needle. The spinal outfit should never be boiled with the other instruments.

7. An assistant removes an ampoule of stovaine from alcohol, in which it has been submerged, and touching it only with a sterile gauze sponge, dries the surface, breaks open the ampoule, and holds it in a convenient position for the surgeon to withdraw the contents.

8. During the injection the patient is firmly held to prevent any sudden movement. The puncture of the skin is made quickly, after warning the patient, and if the patient jerks, the needle is left in place, the patient is reassured, and the introduction then cautiously resumed.

9. The instant the needle is withdrawn from the patient's back, the patient is placed in position for operation upon the table, and the table quickly tilted so as to lower the shoulders two inches below the level of the hips.

10. The patient's hands are held during the operation so that they cannot by any sudden movement invade the field of operation. A towel or sheet is so arranged that the patient cannot cough, sneeze, or vomit over the sterile area.

11. The pulse, respiration, and color are to be as carefully observed as if ether were being given—the respiration by a wisp of cotton affixed to the tip of the patient's nose. If the patient is awake, conversation to divert and encourage the patient should be carried on in a low tone. The patient is not to be informed as to the commencement of the operation, nor should he be asked as to his sensation of pain. If possible, the thought of pain, fear, or danger, should not be suggested by the conversation of bystanders. If not contradicted by the operation, the patient may be entertained by bits of cracked ice, sips of water, or the privilege of smoking. The very apprehensive patient may be diverted by inhaling aromatic spirits of ammonia, or a little ether.

12. The danger signs are marked fall in blood pressure, cyanosis, or respiratory depression. The premonitory sign is nausea or slight gagging. At this sign the table is to be further tilted in order to lower the patient's head and a stimulating ampoule, containing 5 grs. of caffeine and 1/15 gr. of strychnine sulphate, is to be immediately injected into the thigh. Weak patients should be given an ampoule of pituitrin hypodermatically immediately after the spinal injection.

13. The danger period of spinal anæsthesia is from five to thirty minutes after the injection.

14. After operation the patient's shoulders should not be raised until one hour has elapsed from the time of the injection. During this time the patient should not be shaken or roughly handled. No special after-treatment is necessary.

15. A funnel and six feet of rubber tubing connected with a transfusion needle should always be conveniently at hand, with a flask of sterile warm physiological salt solution, a sterile dropper, and a bottle of 1:100 epinephrin solution, and for asthenic patients, the left elbow should be bared, aseptisized, and wrapped in a sterile towel for a possible emergency intravenous injection.

16. Patients who have had narcotics are usually given a one or two quart enema of warm water after being returned to bed. If they are shocked, or deeply stuporous, one dram of tincture of capsicum with six ounces of a strong decoction of coffee is incorporated in the enema.

17. As to the later treatment in abdominal cases, enemas are usually given every four hours for two days. The first day they consist of warm water, 240 ccm.; the second day, epsom salts, 15 ccm., and warm water, 120 ccm. This is irrespective of the anæsthetic.

Mortality following spinal anæsthesia. Various observers have given a mortality varying from one in fifty to one in seventeen thousand injections. In our first five thousand intradural anæsthesias there were ten deaths on the operating table, and one death two days after a difficult resuscitation for cardiac failure under the anæsthetic. All but the last mentioned were hopeless, or nearly hopeless, from the character of the disease, irrespective of the anæsthetic. They included such cases as an aged man dying from neglected perforation in typhoid fever; an elderly alcoholic nearly moribund from gangrene of the thigh and leg following a crushing injury; a man with advanced sepsis from strangulated hernia, intestinal gangrene, peritonitis, and widespread phlegmon of the abdominal wall; a pulseless and extremely shocked patient with an accidental avulsion of the shoulder; an infant with advanced general miliary tuberculosis; a woman with purulent peritonitis of the upper abdomen from a perforated gall-bladder, and with suffocation from regurgitant vomiting; a patient with a massive empyema, marked sepsis, and extensive phlegmon of the thoracic wall.

It is unwise to give spinal anæsthesia to patients who are in a hopeless condition or who are otherwise bad risks. By eliminating the small percentage of patients who fall into this class we have also eliminated all deaths that could be ascribed to the anæsthetic in the last three thousand cases of spinal anæsthesia.

While by skilled use and careful selection of patients spinal anæsthesia compares well in point of safety with ether, the fact that the dose once injected cannot be recalled or prevented from acting, and that the patient's life so closely depends upon the accuracy of dosage and the judgment and skill of the surgeon, clearly should prevent the general and indiscriminate use of this anæsthetic.

SACRAL ANÆSTHESIA

Sacral anæsthesia (epidural, extradural, or caudal anæsthesia) was originated by the Frenchman, Cathelin, and developed by Läwen and Gros. It is produced by injecting a solution of local anæsthetic through the sacral hiatus external to the dura; the solution interrupts conductivity in the nerve roots as they pass from the dura to the bony foramina of the spine. The term "low sacral anæsthesia" is used when the solution involves only the nerves within the sacrum; the term "high sacral anæsthesia" when the nerve roots of the lumbar and dorsal region are affected.

Anatomical considerations. The sacral hiatus lies about 2.5 cm. above the lower end of the sacrum on its posterior surface. It is a lozenge shaped space bounded above by the forked termination of the spinous processes of the sacrum, laterally by the two cornua sacrales, and below by the coccyx. The hiatus is covered by a dense membrane, within which lie the loose areolar tissue and nerves of the sacral canal. The anal groove marks the midline of the hiatus, except when the patient is in a lateral position, when the groove is displaced 1 or 2 cm. toward the surface upon which the patient lies. The termination of the dura is opposite the second sacral vertebra, or about 6 cm. above the hiatus. In injecting the hiatus, therefore, the needle should not be introduced more than 4 cm. for fear of puncturing the dura. Low sacral anæsthesia interrupts conductivity in that portion of the sacral plexus supplying the perineum, the anus, the lower rectum, the urethra and penis, the lower part of the prostate and scrotum, the vagina in the female, but not the testis. By elevating the pelvis after the injection and by using sufficient solution, permeation of the extradural space and involvement of nerve roots even to the lower cervical region may be obtained.

Technique. The instruments required are a 20 – 100 ccm. Luer or Record syringe and a needle about 8 cm. long and about 2 mm. in diameter. Instead of a needle a delicate cannula with a very sharp mandrin may be substituted. The best needles or cannulas are made of platino-iridium, but steel needles or those made of nickeloid, or of hard gold alloy, are efficient. The anæsthetic usually employed is a 1 per cent solution of procaine (novocaine), to every 100 ccm. of which 0.25 ccm. of a 1 : 1000 solution of epinephrin is added. Läwen, believing that an alkaline solution made with sodium bicarbonate is more efficient than one made with sodium chloride, uses a solution of sodium bicarbonate 0.25, sodium sulphite 0.25, sodium chloride 0.5, distilled water 100 ccm. This solution is sterilized, one gram of procaine added, the solution reboiled for one minute, and 0.25 ccm. of a 1 :1000 solution of epinephrin finally added. The sodium sulphite is used to prevent the rapid oxidation of the epinephrin in the alkaline solution.

Dosage. For low sacral anæsthesia the average dose is 0.6 grams of procaine, or 60 ccm. of a 1 per cent solution. The minimum is 0.4 grams or 40 ccm. The average dose for high sacral anæsthesia is 0.7 grams or 70 ccm. of the 1 per cent solution. The maximum dose is 0.8 grams of procaine. In marked anæmia, cachexia, in cases of deep narcosis, in icterus, after severe hæmorrhage, or if the patient weighs less than 105 pounds, the dose is diminished 0.1-0.2 grm. For patients not well narcotized, or those weighing over 126 pounds 0.1 gram of procaine is added to the usual dose (Schlimpert). For a more intense action 1.33 per cent solution may be used.

For low sacral anæsthesia the patient is turned upon his right side with the head slightly elevated and the back well flexed. As one follows down the sacral spine the hiatus is located; the anal groove is displaced about one finger's breadth toward the dependent side of the patient. Under strict aseptic precautions the needle is introduced through the center of the hiatus at right angles to the skin, but, as soon as the membrane covering the hiatus has been punctured, the needle is depressed so that it points upward and lies nearly parallel with the skin surface; the needle is then very cautiously introduced into the sacral canal for a distance of 3 – 5 cm., the stylet withdrawn, and the syringe containing from 40 to 90 ccm. of the 1 per cent solution of procaine affixed. Should there be a flow of blood from the needle upon withdrawing the piston of the syringe the injection must not be given until the needle has been so readjusted that the solution will not enter a blood vessel. The injection is made slowly, taking about 90 seconds, and the proper position of the needle is shown by a lack of resistance to the injection. After the injection the needle is immediately withdrawn and the patient left flat, or with the pelvis slightly elevated. For high sacral anæsthesia the injection is best made in the knee chest position, the pelvis being first elevated thirty degrees, and at the completion of the injection, to forty-five degrees. For convenience in placing the patient in the knee chest position, a special tilting chair to which the patient is strapped has been devised in the Freiburg clinic. This rather elaborate piece of apparatus is not absolutely necessary. To reduce the pain of the injection and to increase the certainty of the method, sacral anæsthesia has frequently been combined with "twilight sleep," the patient being given ½ to 1 gram of veronal on the morning preceding the operation, and from one to three injections of morphine and scopolamine, beginning about one and one-half hours before the time of operation, as described under narcotic anæsthesia.

Efficiency. Low sacral anæsthesia is efficient in about 55 per cent of the cases; high sacral anæsthesia in about 45 per cent of the cases. Sacral anæsthesia has chiefly been employed in obstetric practice, and for greater efficiency has been combined with narcotic anæsthesia. The injection has also been recommended for the relief of sciatica and anal pruritis. While much less efficient as an anæsthetic than spinal anæsthesia, it may be used by those who wish to avoid the greater risk and possible cephalgia from the intradural injection. It is evident that it has such limitations that only very devoted enthusiasts will have the patience to continue its use.

NARCOTIC ANÆSTHESIA

Stupefying draughts have been employed to relieve the pain of surgical operations from the dawn of written history. The most useful drugs are the alkaloids found in poppy and mandragora, plants which were referred to by the earliest medical historians. Using a combination of morphine and scopolamine, Schneiderlin, in 1901, revived this ancient method of producing surgical anæsthesia. Later modified and used chiefly in obstetric practice, the method has had an extended use under the name "twilight sleep." In 1904, to determine the usefulness of narcotic anæsthesia in general surgery, we tried for one month to use no other anæsthetic for operations upon adults. In routine use it was found that about 30 per cent of the patients that came to the operating table could be operated upon with a fair degree of satisfaction. In the remaining patients the method was not satisfactory, for although many of the patients had no recollection of having been in the operating room, their active reflexes and movements on the operating table necessitated restraint and rendered the operation difficult. In from 10 to 20 per cent of the patients the excitement and delirium were so marked, or there was so little narcosis, that the operation could not be done. On reviewing the patients it was found that narcotic anæsthesia was rarely efficient in persons under 30. In young patients the delirifacient action of the hyoscin or scopolamine predominates, while in the elderly or debilitated the hypnotic action is in the ascendant. In children on account of the dangers attending the use of morphine the method is not justified. The senile, toxic, jaundiced, exhausted, or those physically impoverished, are especially susceptible. On account of the associated muscular rigidity the method is not well suited for celiotomy, except in patients with very relaxed or wasted abdominal walls. It is much easier to produce sufficient anæsthesia for operation upon the scalp, skull, brain, face, jaws, neck, and spine, than upon the hands, feet, or rectum. A mixture of the hypnotic drugs, on account of the crossed action, seems safer and preferable to the use of but one or two drugs. Those most valuable are morphine, apomorphine, hyoscin or scopolamine, chloral, paraldehyde, alcohol, ether, veronal, isopral, hedonal, and compound spirits of ether. Wide variations in the personal reaction, especially to scopolamine and hyoscin, have led many observers to conclude that these drugs vary greatly in potency and narcotic action, and have enabled special proprietary preparations to be exploited at exorbitant prices, especially for the production of "twilight sleep."

A variety of methods for narcotic narcosis are feasible. The most commonly used are those involving a combination of alcohol and apomorphine, or of morphine and scopolamine.

Alcohol-apomorphine narcosis. For a young robust adult in acute alcoholic delirium an injection of 1/10 to 1/7 grain of apomorphine subcutaneously, usually so quiets the patient within five minutes that lacerations of scalp or face may be sutured or a craniotomy performed without remonstrance on his part. In a similar narcosis the patient is given by mouth or rectum repeated doses of dilute alcohol or ether followed, as soon as excitation or delirium appears, by the subcutaneous injection of from 1/15 to 1/7 grain of apomorphine, the larger dose being given only in the robust. Usually this is followed by a brief but often imperfect emesis, immediately succeeded by a relaxed insensible condition which usually continues from one to four hours. For the dipsomaniac who requires operation, but has not the courage or logic to request its performance, the method enables the surgeon to operate without the patient's consent. If the anæsthesia is insufficient, additional hypodermic injections with or without morphine and scopolamine, or a small amount of ether by inhalation may be given.

Scopolamine-morphine anæsthesia. We have found the following modification of this method very useful in selected cases. One and one-half hours before the time of operation, the patient, having previously been prepared by baths and laxatives, is given a hypodermic injection of morphine sulphate 1/6 grain, with hyoscin or scopolamine hydrobromide 1/100 grain. Twenty minutes later, unless in the meantime the patient shows marked narcosis, the hypodermic injection is repeated, and immediately after there is slowly run into the bowel a solution containing Hoffman's anodyne one ounce, alcohol one-half ounce, paraldehyde one-fourth ounce, and water to make five ounces. The patient is now constantly watched, and the need for further narcotics determined. In very old, debilitated, or toxic patients, the second injection may not be required. In many elderly or debilitated patients two injections will be sufficient, so that twenty minutes after the enema the patient is in such a condition that he cannot be roused by strongly pinching the skin near the field of operation, and, therefore, is ready for the operation. More frequently, twenty minutes after the second injection the patient is somnolent, but is easily partially aroused. In such a case if the pulse and general condition are good, a third subcutaneous injection is given consisting of:

Apomorphine hydrobromide, 1/20 to 1/10 grain;
Scopolamine or hyoscin hydrobromide, 1/100 grain;
Morphine sulphate, 1/6 grain.

The use of these various drugs is based upon the patient's reaction and susceptibility. If the patient, although not fully narcotized, shows by a red, florid skin, more or less dilated pupils, and delirium, that he has the full action of the scopolamine, this is omitted from the later hypodermics; or if by contracted pupils, slow respiration, and pallor, that a predominant morphine effect has been obtained, then this drug is omitted. If heart action is weak, the patient very asthenic or debilitated, the apomorphine, which is the most powerful of the drugs, must be avoided or used with great caution. The effect of the apomorphine often comes on with startling rapidity. Three to five minutes after the injection of the apomorphine the semi-conscious patient may fall back insensible, so that extensive operative procedures may be begun at once. The duration of the narcosis is from two to eight hours, and the patient usually wakens with no recollection of having fallen asleep or even having awakened, and usually at once begins to inquire when the operation is to be performed. For the comfort of the patient, the method is ideal. It enables an operation to be performed without the patient's knowledge or consent. The narcosis may be started in the patient's home, the patient transferred to a hospital, operated upon and returned to the home entirely oblivious of the fact that he has even been asleep. There is a limited class of patients who desire to be operated without knowing the time of operation, or who avoid or refuse operation through fear, cowardice, alcoholism, or mental perversion. In such cases, if the surgeon is justified in operating without the patient's knowledge or consent, the method is ideal.

Dangers. Narcotic anæsthesia is dangerous and should only be employed by a skilled physician who has the patient constantly watched. The greatest danger is that the tongue may fall back and produce death by a slow asphyxia. In such a condition we have repeatedly found that assistants will inject stimulants and fail to observe the simple expedient of pulling forward the tongue. To impress upon all attendants the constant danger of respiratory obstruction we have a light wisp of cotton affixed by adhesive plaster to the patient's nose as soon as the narcosis begins, the oscillations of the cotton splendidly indicating the degree of respiratory movement. In the uræmic, or otherwise very toxic, patient, especially if he be also aged, the method is especially dangerous and should be avoided, or only used with the greatest care. It should be avoided in subtentorial tumors or other diseases with depression of the respiratory centers, or with any marked degree of abolition of the pulmonary function. Marked toxæmia from sepsis, or advanced renal or hepatic disease, contra-indicate the narcosis. Patients with tuberculosis or moderately advanced carcinoma are often unusually susceptible and frequently very good subjects; in the former case, however, the respiratory depression following the administration of morphine and scopolamine must always be taken into consideration.

Resuscitation. At the completion of the operation, or if the patient is too deeply narcotized, the following enema is given after irrigating the bowel:

Black coffee, 1 pint;
Tincture of capsicum, 2 drachms;
Warm water, 2 quarts.

A hypodermic injection may also be given, containing 1/20 or 1/10 of a grain of strychnine and from 3 to 5 grains of caffein. If cardiac failure or collapse develops, the intravenous injection of one pint of physiologic saline solution containing 5 or more minims of 1:1000 epinephrin solution is given, the flow of the solution being interrupted as soon as the heart responds. For respiratory failure, artificial respiration should be employed. In the average case these special measures are unnecessary and the patient is simply given two quarts of water by rectum at the completion of the operation. To prevent reabsorption of the drug the patient may be catheterized.

A partial narcotic anæsthesia ("twilight sleep") is frequently of great advantage in conjunction with local, spinal, sacral, or other forms of conduction anæsthesia. In obstetric practice it is very difficult to produce a uniform narcosis and the child is frequently dangerously stupefied.

SECTION III

AMPUTATIONS

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CHAPTER I

INDICATIONS: DANGERS: GENERAL PRINCIPLES: PRINCIPAL METHODS OF CONTROLLING HÆMORRHAGE: AND THE PRINCIPLES OF OPERATING

Varieties. In connexion with the extremities it has been the custom to use the term 'amputation' to denote any operation by which a limb or any integral portion of a limb is severed from the rest of the body. It is, however, preferable to subdivide amputations into two distinct groups, viz. (i) *Amputations* proper, or those in which the limb is removed after division of bone, and (ii) *Disarticulations,* or those in which removal is effected through one of the joints. The decision as to whether the surgeon will perform a true amputation in preference to a disarticulation in any given case will be influenced as a rule by the special circumstances connected with the injury or disease for which the operation is required, but certain points should be borne in mind when the conditions allow the surgeon his choice between the two.

Speaking generally, it may be said that, owing to the larger size and smoother contours of the articular ends, they furnish the best surfaces upon which pressure may be borne in the lower extremity, or from which purchase may be taken for the movements of an artificial limb in the upper extremity, and that therefore a disarticulation should be preferred to a true amputation when either of these points is of cardinal importance. When, however, the object is to obtain the most perfect æsthetic result, it has to be remembered that after a disarticulation it is impossible to fit an artificial limb which will preserve the normal movements. Thus, for instance, if a patient be fitted with an artificial limb after a disarticulation at the knee-joint, and the limb be furnished with an artificial knee-joint, this must necessarily be on a lower level than the one on the sound side in order to permit of flexion; therefore, although the difference in the level of the knee-joints on the two sides may pass unnoticed when the patient is upright or walking, it becomes apparent at once when the knee is bent, as in sitting down. For this reason most instrument-makers prefer a stump resulting from an amputation through the condyles of the femur to one left after a disarticulation at the joint, although obviously the basis of support in the latter case is larger and more stable than in the former; this point, however, is dealt with more fully later on.

Indications. In former days it was much easier to define exactly the cases that called for amputation than it is at the present time. There are still a few groups of cases in which amputation must always be resorted to, but the limits of the very large group in which amputation is only occasionally required are still vague, and are constantly changing with the advances made by conservative surgery. Owing to the great improvement not only in the actual treatment of wounds, but also in the various other directions which have been opened up by the improved methods of securing asepsis, such as nerve suture, bone, tendon and skin grafting, &c., it has become possible to save and make useful members of limbs that were formerly condemned. The cases, therefore, in which amputation may be done will be considered in two large groups—(A) those in which amputation is invariably required, and (B) those in which it is only occasionally called for.

(A) Cases in which amputation is always required. (i) *Avulsion of a limb.* Here there can be no question as to the necessity of amputation, since the limb has been actually removed by the agent causing the injury, and the operation generally resolves itself into some form of 'trimming' operation, having for its object the removal of the damaged tissues together with enough bone to allow the skin to be brought together neatly over the end of the stump.

(ii) *Malignant disease of bone.* When malignant disease attacks a bone some form of amputation is absolutely necessary; for choice this should take the form of disarticulation at the joint above the seat of the growth, so that the entire bone and its lymphatic supply shall be removed. In the extremities, at any rate, it is hardly ever wise to remove only a portion of the bone, as recurrence under these circumstances is almost inevitable. This statement, however, does not include the so-called myeloid sarcoma, which is of low malignancy, and for which a much more limited operation, such as enucleation of the growth, or, at the most, an amputation through the bone immediately above the upper limit of the growth, will suffice.

(iii) *Severe crush-fractures.* These are the cases in which there may be the greatest difficulty in deciding whether to amputate or to try to save the limb. The old rule that amputation should be practised when either the main artery, vein, or nerve were divided no longer holds good, neither does the dictum that extensive laceration of the skin demands amputation. Also, a wound of a neighbouring joint may often be treated safely by disinfection and drainage, and the limb preserved, even when considerable portions of bone have been comminuted or entirely destroyed, as in gunshot injuries; thanks to modern methods of splicing and grafting bones, a useful limb need not be despaired of. It is obvious that amputation will be necessary if the main artery, vein, and nerve have all been damaged, but, provided that one of these structures remains intact, the position of affairs is not hopeless. Collateral circulation may be restored even after damage to both artery and vein, whilst, if these structures be intact but the nerve be divided, the extra time necessary for suturing the nerve does not materially add to the gravity of the case. Even when the skin has been extensively destroyed, the application of Thiersch's skin grafts, either immediately after the accident or at some subsequent period, when it is seen how much of the skin will die, will often give the patient a useful limb which would otherwise have been sacrificed.

(B) Cases in which amputation is only occasionally required. (i) *Gangrene.* Some form of amputation is nearly always necessary in cases of gangrene, except in the slightest type of the senile variety, and in those trivial cases that accompany Raynaud's disease, frost-bite, and the application of heat or caustics. Even when the gangrenous part is allowed to separate spontaneously, some form of amputation is necessary, as the surgeon will be obliged to cut away portions of the protruding bone in order to get the soft parts to meet comfortably over it. The particular period of the disease and the exact situation in the limb at which the amputation should be practised must necessarily vary with the affection which calls for amputation; the important point is that it should be done in a situation where the blood-supply is good. Thus, for instance, it is useless to amputate through the foot or leg in senile gangrene, owing to the indifferent vascularity of those parts; the amputation should be done either in the region of the knee-joint or through the lower third of the thigh, as otherwise gangrene of the flaps is likely to occur. This is the principal risk of amputation in cases of gangrene, and it is increased enormously by the occurrence of sepsis, which leads to a rapidly spreading septic gangrene that is very fatal. There are of course other risks incidental to special cases, such as diabetic coma in cases of gangrene in diabetics.

(ii) *Compound fractures.* The remarks made concerning bad crush-fractures (*vide supra*) will serve to indicate the type of cases that require amputation in this kind of fracture. Few, if any, ordinary compound fractures, even if they extend into the neighbouring joints or are accompanied by occlusion of the main artery or vein, or division of the main nerve alone, are looked upon as suitable for amputation nowadays. In arriving at a decision in these bad cases the surgeon must take into consideration the age, the general health, and even the social position of his patient, before he can judge whether amputation or conservative surgery is the better line of treatment. In addition to this, the most important point of all, namely the possibility of keeping the wound aseptic throughout, must not be lost sight of, and this question will be influenced to some extent by the considerations previously mentioned. Old age, with its liability to shock, to lung mischief from confinement to bed, and to bed-sores, together with the depressing influence of a prolonged convalescence, is against a too strenuous attempt to save a limb that must necessarily require a long period for healing. An amputation followed by primary union and necessitating only the minimum confinement to bed will often prove far better for an aged patient than too persistent attempts to save the limb. The situation of the fracture, and therefore the possibility of keeping the parts at rest effectually, or the wounds free from infection, also bear strongly upon this point, as do also the social circumstances of the patient. It is of primary importance that if an attempt be made to save the limb in bad cases of compound fracture, the conditions should be such that there is very little likelihood of sepsis supervening. Lastly, the character of the limb when it is eventually saved must be taken into consideration. A stiff limb, which is constantly liable to ulceration, although it may satisfy a well-to-do patient who can take all due care and can have all requisite attention, will be worse than useless to a working man, in whom the exact opposite is the case. In cases of doubt, however, it is well to remember that conservative surgery should have the benefit of the doubt, as it is always possible to amputate at a subsequent period should circumstances render it advisable.

(iii) *Intractable joint-disease.* Many cases of joint-disease require amputation. Foremost among these are suppurative arthritis, either acute or chronic; in the former case to avoid general pyæmia, and in the latter lardaceous disease. Tuberculous joint-disease also calls for amputation when it is too extensive to be dealt with by excision, and particularly when the limb is riddled with septic sinuses; here amputation not only removes the disease, but eliminates the possibility of lardaceous disease and restores the patient to health after a comparatively short convalescence. Amputation is often necessary in weakly persons who are the subject of advanced tuberculous disease, especially when there is tuberculous mischief elsewhere, as recovery from amputation is shorter, and makes less tax upon the general powers than does the protracted convalescence following a severe operation like excision.

(iv) *Intractable suppuration in an extremity.* Owing to improved methods of wound treatment, intractable suppuration in an extremity is much rarer than it used to be; there are, however, certain groups of cases in which it is still a prominent feature, and which can only be treated satisfactorily by amputation. Such cases, for instance, as those of acute infective osteomyelitis in which the whole of one of the long bones is implicated frequently demand removal of the limb; and amputation through the arm or forearm is still resorted to fairly often in the treatment of intractable cellulitis of the hand and forearm following whitlow. This serious affection, however, is becoming less formidable nowadays, owing to the earlier diagnosis and improved methods of treatment by the various sera, &c. Amputation, on the other hand, is of little or no service in these fulminating septicæmic cases, in which the organisms are disseminated rapidly by the blood-stream without the formation of any considerable focus at the point of infection; this type is a general blood-disease, and removal of the focus of infection is not only of no avail but actually adds to the patient's danger by reason of the shock it gives rise to.

(v) *Certain cases of deformity.* There are a number of cases of deformity, congenital or acquired, in which amputation is done either to obtain an improved æsthetic result or to provide the patient with a firmer basis of support for locomotion. Thus stiff fingers after whitlow, and certain deformities after burns, &c., are often treated by amputation, although the wider application of skin-grafting has reduced the number of these cases considerably. Amputation, however, is often very useful in treating the severe deformities following infantile paralysis, in which the limb, besides being useless for the purpose of support, suffers from defective nutrition, which renders it a constant source of discomfort and danger to the sufferer.

(vi) *Ulcers.* Many chronic ulcers of the leg are seen in the outpatient departments of hospitals in which a permanent cure is not to be looked for. When the ulcer is of many years' standing, and is so extensive that it encircles the limb either entirely or in great part, there is little hope of obtaining a satisfactory result by any method of palliative treatment. The circulation, both systemic and lymphatic, is so much interfered with by the chronic inflammatory process in and around the ulcer, that not only is it almost impossible to promote complete cicatrization by any means, but, even should this end be attained eventually, the ulcerative process will recur on the very slightest provocation, and the time spent in securing healing will be expended in vain. The application of Thiersch's grafts to these ulcers has done much to secure rapid healing, but in the extensive cases under consideration widespread sloughing and recurrence of the ulcer in all its former extent will frequently take place after it, even though the most elaborate precautions be taken to prevent it; and, as these intractable ulcers occur only in the poorer classes, to whom confinement to bed generally means loss of wage-earning, the matter is one of great seriousness.

Amputation affords the only rapid and certain cure in these bad cases, and the particular form of amputation required will generally be one at the 'seat of election' (see p. 333), on account of the situation of the ulcer. This should be recommended for extensive ulcers of long standing that almost entirely surround a limb and are accompanied by much induration of the non-ulcerated parts in the immediate vicinity, but it must be admitted that the patient will rarely accept the advice, preferring the inconvenience and pain of the ulcer to the loss of the limb.

Dangers. Nearly all the risks attaching to operations in former years have disappeared now, as a result of the improvements in the treatment of wounds; practically the only real danger attending the removal of a limb is *shock,* and this only occurs when the operation is one of considerable magnitude. It is well known that the degree of shock varies with different operations. It is much more marked in amputations of the lower extremity than in those of the upper; in the latter region it is seldom met with, whilst in the former the old rule still holds good, that the severity of the shock increases directly with the nearness of the amputation to the trunk. This rule, however, must be qualified to the extent of saying that the degree of shock met with does not constitute any real risk to life except in a few of the more severe amputations, such as amputation through the upper third of the thigh, or disarticulation at the hip joint. Modern methods of guarding against shock will suffice to avert the danger of a fatal termination in all cases except those just enumerated; in them there is no doubt a definite mortality directly resulting from the severity of the operation. The exact percentage cannot well be estimated, as sufficient data are not obtainable; but that cases of death from pure shock, as distinct from those due to hæmorrhage or early sepsis, do still occur after the major amputations in the lower extremity must be admitted by all practical surgeons.

The shock resulting from these major amputations appears to be due mainly, if not entirely, to the division of the large nerve-trunks close to the body, and there is a most remarkable difference in the mortality of such an operation as disarticulation at the hip joint when the operation is done, on the one hand, by a method such as Furneaux Jordan's (see p. 366), that involves division of the vessels and nerves completely low down in the thigh, and on the other, when it is done by one such as the anterior racket method, which necessitates their division on a level with Poupart's ligament. Allowing for the elimination of deaths from early sepsis, the mortality in these latter cases is still nearly as great as it was in former times. Since the shock appears to be due to the division of the nerve-trunks, and since the experience of those using stovaine and other local analgesics tends to show that these substances abolish shock much more than does a general anæsthetic, it would appear that the mortality of these severe amputations may possibly be diminished in the near future by the use of one of these local analgesics, either injected into the nerve-trunks at the point of section, or into the vertebral canal itself. Full details upon this subject will be found in Section II.

That the shock, however, is not entirely due to division of nerve-trunks close to the nerve-centres is proved by the fact that there is much less shock met with after the extensive interscapulo-thoracic amputation of Berger (see p. 270) than after disarticulation at the hip-joint by the anterior racket method, which is still not infrequently accompanied by fatal shock. This serious danger of shock must therefore be guarded against by every means in the surgeon's power; of these the most important is rapidity of operation, and no case of this kind should be undertaken unless the surgeon is provided with plenty of skilled assistance, and can operate in surroundings that are most favourable to minimizing shock.

The possibility of increasing or inaugurating shock by traumatization of fat in the subcutaneous tissue or in the bone should not be forgotten. That fat embolism is the distinct cause of shock in certain cases cannot be denied. This is especially true in thigh amputations where the fat is frequently excessive.

I have recently adopted a modified Trendelenburg position for operations about the pelvic region and lower extremity that are likely to be accompanied by severe shock, and I have been much pleased with the results; shock seems certainly to be diminished to an appreciable extent, and moreover there appears to be less oozing from the wound, especially in cases of amputation. In these latter cases the true Trendelenburg position is difficult to use, owing to the undue height of the pelvis and the necessity of getting the sound limb out of the way, but if the operating table be so constructed that the head of it can be lowered, instead of the pelvic portion being raised, a similar effect can be obtained to the true Trendelenburg position. If such a table be not available the surgeon will need to stand upon a suitable stool.

Shock as influencing the time of amputation. It happens occasionally, particularly in severe machinery, gunshot, or railway injuries, that a patient who is the subject of a crush-fracture that inevitably requires amputation comes under the surgeon's notice in an almost moribund condition from the excessive shock due either to the injury to the limb alone or to the combined effects of that and some severe internal lesion. The question that arises is, Shall amputation be performed at once, or shall an interval be allowed for a certain amount of rallying to take place? This question in the past has generally been answered by saying that amputation should be postponed until enough reaction has occurred to warrant the surgeon in thinking that the operation can be borne successfully.

This opinion is still held by a majority of surgeons, although I myself have leaned to immediate operation.

That nerve irritation plays a large part in shock is generally believed. Therefore, the early injection of the nerves or their roots in the spinal canal with novocaine or its congeners is indicated. If the extremity is attached by a few shreds of tissue, its removal at the same time is justified. If operation is deferred, these injections should be repeated until the patient has recovered sufficiently to justify the intervention. The amputation should be done as expeditiously as possible and with the slightest possible psychic and physical shock. The usual methods of stimulation, heat, rest, infusion and transfusion, should be employed.

At present, however, we have in Spinal Analgesia a most valuable means of combating shock of this kind. It is remarkable how much the general condition improves after its employment; pain ceases, the pulse improves, and the restlessness disappears. The amputation may be undertaken forthwith, and the danger inseparable from a general anæsthetic is absent. It is precisely in this group of cases that spinal analgesia finds one of its most brilliant applications, and it should be employed in these cases to the exclusion of general anæsthesia. The patient is so deeply under the effect of the primary shock that he will be probably quite indifferent to the pain of the lumbar puncture.

It is true that these considerations apply only to the lower extremity, and that in the present state of our knowledge we cannot get safe spinal analgesia for similar work in the upper limb. It must be remembered, however, that the shock is hardly ever so severe in the case of the upper extremity, and that it will generally be possible to use some general anæsthesia such as ether here, provided that eucaine, stovaine, or some other local analgesic be injected into the nerve-trunks and that only the smallest possible quantity of ether be used. The important point is that the limb should be removed rapidly, and so a potent source of prolongation of the shock removed.

Hæmorrhage, which was formerly a serious danger in these cases, is now of little importance, owing partly to the introduction of anæsthetics, which allows of greater deliberation in operating, whereby it is possible to secure the main vessels in certain cases before dividing them, and partly also to the universal adoption of the aseptic treatment of wounds, as a result of which sepsis and its frequent accompaniment, secondary hæmorrhage, have become practically non-existent. In situations where it is difficult or impossible to secure proper compression of the main vessels by a tourniquet, such, for example, as disarticulation at the hip and shoulder joints, the surgeon can deliberately expose and secure the vessels before he divides them, and therefore is not obliged to trust to digital compression by an assistant, as he had to do in former times, when no anæsthetic was employed and the operation had to be done therefore with great rapidity; a serious risk of hæmorrhage is thus avoided.

Sepsis should be practically unknown at the present day, even in the most serious cases. Even when the operation is practised near parts that it is impossible to sterilize, it is possible to avoid sepsis altogether by choosing a form of amputation in which the cicatrix is as far removed as possible from any source of infection, as, for instance, disarticulation at the hip-joint by the anterior racket incision. It must not be forgotten, however, that a large amputation, such as one through the thigh or at the shoulder, requires the utmost vigilance in avoiding sepsis, and, should infection occur, the result is likely to prove disastrous, owing to the large size of the cut surfaces and the rapidity with which septic absorption takes place.

General principles underlying amputations. Several other important principles must be remembered if an amputation is to be performed with complete success. Chief among these are the means of obtaining a satisfactory stump, the methods of controlling hæmorrhage, and the general principles underlying the fashioning of flaps. Besides this there are certain general rules to be remembered in connexion with the dressing of the wound and the after-treatment of the stump, including in this the fitting of artificial limbs.

When, however, a surgeon sees a case in which the question of amputation has obviously to be discussed, the first question that he has to decide is whether amputation shall be performed or whether some form of conservative treatment shall be adopted. Should he decide in favour of amputation, the next important step is to formulate clearly in his mind his reasons for choosing the particular form of amputation he decides to adopt in the case before him. We shall consider these two points separately. The first one has been discussed already in connexion with the indications for amputation (see p. 178), but it will be well to recapitulate them here.

Amputation *v.* conservative treatment. Amputation is, or should be, always followed by primary union and rapid convalescence, and therefore it is suited for those cases of tuberculous disease, gangrene, or crush-fracture in which the advanced age or feeble general condition of the patient, or the absence of suitable hygienic surroundings, &c., makes it clear that a prolonged convalescence would probably extinguish the sufferer's chances of recovery. Striking illustrations of this are seen in the rapid and permanent restoration to health when amputation has been done for intractable suppuration or bad tuberculous bone-disease. Age in itself is not a bar to conservative treatment, but the question of shock is influenced to a large degree by that of age, and elderly patients bear severe shock badly; therefore a prolonged and difficult operation, such, for instance, as excision of one of the large joints, is likely to be dangerously severe in an old patient, and an amputation is much to be preferred.

The patient's occupation also has some bearing upon the question. When the adoption of conservative treatment must necessarily involve a long illness, possibly leaving the patient with a stiff limb that will be a hindrance in his daily work, it may suit his purpose better to have a sound and thoroughly useful stump instead of a stiff and useless limb. An example of this may be seen in certain cases of chronic ulceration of a varicose leg, which the most painstaking conservative treatment fails to keep healed for more than a few weeks or months at a time, and then only after prolonged confinement to bed. Amputation in these cases rids the patient of a painful and troublesome sore at once, and renders him able to do his work without interruption.

Constitutional disease, although formerly considered of great importance, exerts but little influence nowadays in deciding the question as to whether amputation shall be performed or not; it has, however, some bearing upon the choice of the particular form of amputation chosen (see p. 180).

The particular form that the amputation shall take must be influenced by a number of considerations. In the first place, the exigencies of the situation may call urgently for one of the more rapid and easy forms of amputation, possibly involving the sacrifice of portions of the limb that would otherwise be saved were the surgeon able to proceed more deliberately and under more favourable circumstances; good examples of this are met with in military surgery, where rapidity is often all-important. The sex of the patient also occasionally, but rarely, influences the question; for example, in amputation of fingers the appearance of the hand may be of more importance to a female patient than its strength, and the surgeon may therefore choose an operation designed to restore the symmetry of the limb as much as possible, in preference to one which has for its object the maintenance of the full strength of the hand so essential to working men. The social position or the occupation of the patient may also have to be considered. In working men a firm basis of support, which is capable of withstanding all the pressure to which the stump is likely to be exposed, is of primary importance; in well-to-do patients, on the other hand, for whom all the resources of the instrument-maker's art can be invoked, length of stump or strength of limb may be sacrificed to improved appearance. Disarticulation through the knee-joint, for example, furnishes a most serviceable stump suitable for working men, but it is disliked by instrument-makers because of the impossibility of fitting it with an artificial limb that shall have the artificial knee-joint on the same level as the natural one.

In amputations of the hand and fingers the greatest conservatism should be enforced—even a part of a thumb is of much greater value than any form of mechanical appliance. A single finger may be removed completely for cosmetic purposes if others are left, but when several fingers are involved, every fragment must be saved, since the adaptation of these stumps to functional purposes is most remarkable.

The most important point, however, in the majority of cases is to adopt whatever form of amputation will give the patient a perfectly sound stump and at the same time will entail the least sacrifice of parts. The longer the limb the better is the functional power afterwards, as a rule; but this point must be subordinated to the necessity of securing a good stump. It will be necessary, therefore, to consider the qualities of a good and the defects of a faulty stump.

The characters of a good stump. A good stump will be of proper shape, sound and healthy, and it must be as serviceable to the patient as it is possible to make it, so that when fitted with an artificial limb it will attain the maximum of usefulness.

A stump cannot be sound and healthy unless it possesses properly proportioned covering for the end of the bone. If the flaps be cut too short they can only be made to meet over the bone with a certain amount of tension, and this causes them to become adherent and painful. On the other hand, if the flaps be too long, the fault, although not so vital as the opposite condition, nevertheless is somewhat serious, as it not only may endanger the vitality of the parts from defective blood-supply, but it necessitates drainage for a longer period, and a considerable time must elapse before the parts shrink and become sufficiently consolidated to bear the proper amount of pressure. These remarks apply especially to amputations in the lower extremities, but they are also applicable in some degree to amputations in the upper limb. The soft parts should be freely movable over the end of the bone, and the cicatrix itself should not be bound down to that structure. A scar closely adherent to the bone is a constant source of trouble and inconvenience, as it is always liable to ulceration from direct pressure or from friction between the bone and the artificial limb. Moreover, an adherent scar is likely to be unduly sensitive from the irritation of nerve-ends which are caught in it, and it is not at all uncommon for cases of adherent cicatrix to require a secondary amputation for the relief of this condition. At the end of the operation the flaps should come together without the least sign of tension, because a certain amount of retraction takes place during healing, and flaps that can only just be made to meet at the time of the operation are likely to give trouble at a later period; the flaps are pressed against the end of the bone and are thereby irritated, an undue amount of granulation tissue forms as a result of this, and stiff adherent flaps ensue. The end of the stump should be firm in consistency, and, as far as possible, symmetrical in shape, as this greatly facilitates the fitting of a satisfactory artificial limb.

In fashioning the flaps due regard must be paid to the region of the stump upon which pressure will have to be borne when an artificial apparatus is fitted, and an effort should always be made to provide that surface, if possible, from the surface of the limb best calculated to bear pressure. Thus, for instance, the tissues of the sole of the foot, the palm of the hand, or the extensor surfaces of the lower extremity, stand pressure more satisfactorily than do the tissues on the opposite aspects of the limb. Again, it must not be forgotten that a stump is not likely to be satisfactory unless its vascular supply is good, and no form of amputation should be entertained that does not provide for this. This point is not of much importance in healthy subjects, as almost any form of amputation will be followed by satisfactory union in aseptic cases, but in diseased conditions it is of primary importance not to amputate through a region in which the blood-supply is likely to be insufficient for the needs of the tissues. In senile gangrene, for instance, amputation through the foot or the leg is very likely to be followed by sloughing of the flaps from insufficient blood-supply, whereas an amputation through the knee-joint will probably be successful owing to the more abundant vascularity in the latter situation. The blood-supply of the flaps may also be interfered with after the operation by undue pressure from the splint or by too tight bandaging. Lastly, when skin flaps are being raised their blood-supply must not be imperilled, as it easily may be, by raising the skin only and leaving the deep fascia behind, and the edge of the knife must always be kept at right angles to the surface that is being cut, so as to avoid undercutting the flaps and damaging the blood-supply. In certain amputations, such as Syme's, it is easy for a careless operator to prick the posterior tibial artery, which is the main source of blood-supply to the flap, and thus endanger its vitality.

The position and characters of the cicatrix are also matters of importance, for there are few complications after amputation worse than a persistently painful scar. Stress has been already laid on the importance of cutting the flaps so as to obviate this complication, and attention has been drawn to the fact that the flaps must be so planned that the cicatrix lies out of the way of any pressure to which the stump may be exposed when the patient is fitted with an artificial limb.

Another matter of some importance is that the divided bone-ends should always be fashioned so as to enable them to bear pressure without causing irritation to the soft parts covering them. Thus, for instance, in a Syme's amputation the malleoli are cut off in order to provide a horizontal surface upon which the limb can rest. In other amputations sharp edges and spicules of bone are clipped away, and the sharp crest of the tibia is always bevelled off. To some extent this rounding-off process occurs in all cases of amputation, the medullary canal being plugged by a firm mass of bony or fibrous tissue, but careful management is necessary to obtain the best results in the shortest time. The entire shaft of the divided bone wastes considerably unless the weight of the limb is transmitted directly through it.

In this connexion it is perhaps well to consider the question of the formation of a cuff of periosteum, which was originally introduced with the object of closing in the medullary canal, and so preventing sepsis from spreading along it. In this method the periosteum is first peeled back and then drawn over the end of the bone. If properly done, this procedure will end in producing a callus around the cut end of the bone that will aid materially in weight bearing. In many cases, however, small fragments of periosteum become shredded and displaced and favour the development of spicules of bone, thus producing the very conditions it is desired to avoid. When the indications call for the simplest effective technic, the periosteum and the bone should be divided in the same plane, and care taken to remove any periosteal shreds present. Clinical results seem to indicate, however, that the aperiosteal method (Bunge) is more likely to give an end-bearing stump, even in the presence of infection.

In this method 1 cm. of the periosteum is removed from the end of the bone and the marrow curretted out for the same distance. Care must be taken not to remove too much of either the periosteum or the marrow in order to avoid the danger of a localized osteomyelitis in the end of the shaft. The osteoplastic method seems to offer an ideal technic but it is obviously unsuited to any other than ideal conditions.

The characters of a faulty stump. A stump may be unsatisfactory for many reasons. If the flaps be cut too short the skin will be scanty, and may be so stretched that its circulation is interfered with and it is permanently ill nourished. A similar result may follow sloughing of flaps which were originally quite long enough; the remainder becomes tightly stretched over the end of the bone. The scar also may be a source of discomfort, pain, or danger. If it is exposed directly to pressure from the artificial limb and is thereby constantly irritated, it will break down and ulcerate or become warty or hypertrophic, and eventually may be the starting-point of an epithelioma. An ulcerating cicatrix may occur in a stump in which the flaps have been cut too short; it is also occasionally met with after an amputation done through badly nourished tissues, as in cases of infantile paralysis. A painful stump is another source of great suffering to the patient. The most common cause of this condition is the implication of the severed ends of the main nerves in the cicatrix; these become bulbous, and intense pain is experienced on the slightest pressure, so that it is impossible for an artificial limb to be worn. A similar condition may follow septic mischief in the stump. This can be avoided if the nerve be drawn down out of its sheath and at least an inch excised. Ritter has suggested that in addition a Λ-shaped piece be cut out of the end, so that it appears like a fish tail. This is a valuable addition.

Conical stump. In former days this was a fairly common sequela of amputation, and it is occasionally met with even now. The amputation stump, which was satisfactory at the time of operation, becomes shrunken and pointed, the end of the bone forming the apex of the cone and being adherent to the cicatrix, which is often tender, painful, and ulcerated. As time goes on, this condition increases in severity, and often ends in exposure and necrosis of the bone-ends, so that the only remedy is to re-amputate higher up. It is sufficient to mention the causes of this condition to indicate the means of avoiding it. Perhaps the commonest cause is cutting the flaps too short at the time of the operation, so that they can only be drawn together with considerable tension; healing may take place satisfactorily, but during the consolidation of the stump a certain amount of shortening of the skin and muscles takes place, resulting in the formation of the conical stump. Another cause is sloughing in an otherwise correctly fashioned stump; this is a less frequent cause than it was formerly. Apart from these two causes there are cases, especially in growing children, in which the amputation stump, although quite satisfactory at the time of the operation and during the period of healing, becomes conical as time goes on; this is owing partly to the continued retraction of the muscles, but probably mainly to the excessive growth of the bone out of all proportion to the rest of the soft parts. This condition only occurs in growing subjects, and can only be guarded against by making the flaps full long at the time of the operation. It is not, however, a condition of such seriousness, as it is easy to amputate higher up when the degree of conicity of the stump is so great as to threaten ulceration of the scar over the bone, or when the growing period has ceased, after which the condition will not recur. Before that time, however, recurrence of a conical stump has been known after a second or even a third amputation.

Methods of controlling hæmorrhage. Many methods are employed to control bleeding during an amputation; they may be classified as follows:—

(i) **Digital compression.** This is the simplest plan of all, and is in common use for the smaller amputations, such as those of the fingers, in which the circulation can be efficiently controlled by gripping the lateral surfaces of the digit firmly between the thumb and forefinger so as to occlude the digital vessels.

Digital compression was frequently employed in former times in amputations so high up the limb that a tourniquet could not be used because of the risk of its slipping. In disarticulations at the hip and shoulder joints, for instance, it was usual to have the main vessel controlled by the fingers of an assistant. This was done by pressure made over the skin or through an incision directly over the vessel. It is needless to say that to render this uncertain method safe a skilled assistant is required whose fingers will not get tired; it is very difficult to maintain efficient pressure for any length of time, and the least relaxation of pressure may give rise to dangerous bleeding. If digital compression be employed the surgeon must perform his amputation rapidly, and hence it has fallen largely into disuse now that rapidity is no longer regarded as one of the chief essentials in amputating.

Another method of digital compression, namely that in which the assistant slipped his fingers beneath the flap containing the main vessels as the surgeon cut it, and compressed the vessels in it between his thumbs and fingers, has almost disappeared from present-day practice, largely owing to the abandonment of amputations by transfixion. Like the previous method, this requires a skilled assistant thoroughly used to perform the responsible duty entrusted to him.

(ii) **Temporary ligature.** A substitute for digital compression that has come into vogue recently is the use of a temporary ligature applied to the main vessel. Thus, for instance, in disarticulation at the hip or shoulder the common femoral or the subclavian vessels may be exposed, and a loop of silk or tape passed around them; traction upon this loop kinks and occludes the vessels, and it is easy to maintain this traction throughout the operation. The method is perfectly effectual in arresting the circulation, and experiments show that a temporary ligature of this kind does no appreciable damage to the vessel-wall. Under certain circumstances, as, for instance, where special apparatus is not available, the method may be made use of. It has the obvious disadvantage that it entails an extension of the original operation, in that a separate incision is required to expose the vessels above the point at which they will be divided; both the artery and its companion vein should be included in the ligature. When the main vessels have been ligatured on the face of the stump, the temporary ligature is withdrawn and the wound made for its passage round the vessel is sutured.

(iii) **Preliminary permanent ligature of the main vessels.** This method forms an integral part of certain operations, such as disarticulation at the hip by the anterior racket method, and also in Spence's disarticulation at the shoulder as it is usually practised nowadays. The main vessels, both arteries and veins, are exposed by an incision which subsequently forms part of the amputation incision, and are secured and divided between two ligatures; the cut ends are then turned out of the way, and the amputation is proceeded with. This is an exceedingly valuable method, particularly in disarticulation at the hip, as ligature of the common femoral controls nearly all the bleeding from the flaps, and in addition the vessel is easily exposed and tied, while it is not easy to secure it with certainty by any other means.

(iv) **Circular constriction of the limb.** This very old method has been simplified and improved by Esmarch. In its original form a band encircling the limb and provided with a screw-down apparatus which could exert direct pressure over the main artery, was applied circularly round the limb at the desired level. As this form of tourniquet depends for its efficacy upon the correct application of the pressure pad over the artery, and as it is quite possible that this may slip during the course of the operation, the method has manifest drawbacks, and Esmarch's plan of arresting the circulation entirely by stretching an indiarubber cord transversely around the limb is in all ways preferable. Esmarch used the rubber cord in conjunction with an elastic bandage wound spirally up the limb from the extremity to the level at which the transverse ligature was to be applied; this was done with the view of emptying the limb of blood as far as possible, and so preserving to the patient an amount that would otherwise have been lost. This plan is excellent in all cases except those in which the spiral compression of the limb is likely to drive other substances than blood back into the circulation, for example, infective organisms or growth. In these cases a simpler plan is that recommended by Lord Lister, who found that by elevating the limb for about five minutes without employing any compression at all, the extremity became bloodless from reflex contraction of the vessels, and the object aimed at by Esmarch was attained without danger.

The circular indiarubber band is put on the stretch before it is applied, and its centre is placed over the main artery of the limb and the rest of the band is then wound firmly round the limb three or four times, the ends being tied together or secured in forceps. The band should be sterilized by boiling, and its thickness will vary with the size of the limb to which it is to be applied; a stouter band will be required for the thigh than for the upper arm. Unless the surgeon has enough assistants to allow him to tell off one especially to look after the tourniquet and nothing else, the part of the limb to which the band is to be applied should be purified as carefully as the actual area of operation; it is necessary to loosen the tourniquet during the operation, and the risk of infecting the flaps will be very great unless this part of the limb has been made aseptic. The bandage should be applied round either the thigh or the upper arm, and not the forearm or leg; in the latter situations the vessels lie deep between the two bones which protect them from compression. Some experience is needed to apply the tourniquet efficiently without damaging the structures that it compresses; if it be wound too tight, thrombosis of the vein or damage to the nerves may occur. It should be applied just tightly enough to arrest the arterial circulation, as tested by feeling the pulse below. Another useful application of this tourniquet is as a figure-of-eight around the groin and pelvis in disarticulations at the hip, such as Furneaux Jordan's.

This method is very useful and of wide application; it requires no expert assistance or elaborate apparatus, and its chief disadvantage is that it is not applicable to amputations higher up than the middle of the thigh or upper arm. It is apt to give rise to rather persistent oozing when its pressure is relaxed, due apparently to the vaso-motor paralysis that it necessarily produces. In order to minimize this inconvenience the tourniquet should be removed as soon as the main vessels have been secured on the face of the stump; by the time that the ligatures have all been applied the oozing will probably have ceased.

(v) **Hæmostasis by special apparatus.** Much ingenuity has been expended in devising mechanical methods for preventing hæmorrhage when an Esmarch bandage is inapplicable. The most difficult cases are disarticulations at the hip and shoulder joints, and various special forms of apparatus have been invented for use in these operations.

None of these are wholly satisfactory, and, inasmuch as they all involve small preliminary operations for their proper application, they do not seem to offer any material advantage over the more certain method of ligaturing the main vessels before the actual amputation is undertaken or, when that is impossible, of securing the main trunk above by means of a temporary ligature. The only real advantage that these forms of apparatus possess is, that they enable the surgeon to dispense with a certain amount of extra assistance.

Pressure Forceps of Lynn Thomas. This is a convenient method of temporary compression that resembles Esmarch's bandage in so far

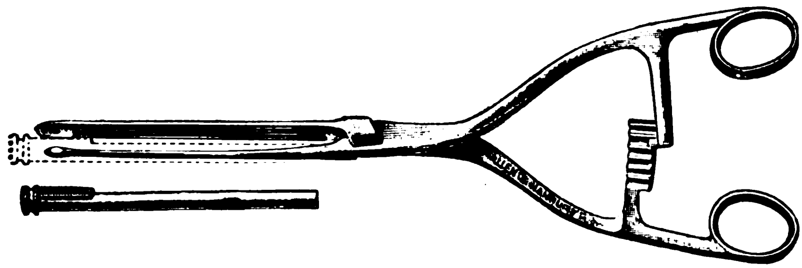

FIG. 35. LYNN THOMAS'S HÆMOSTATIC FORCEPS. The probe-pointed blade underruns the tissues to be compressed; the flat grooved one exerts pressure over the skin externally. The hollow tube figured below is only used on the battle-field to protect the probe-pointed blade from contamination.

as it compresses certain portions of the stump tissues *en masse*. The forceps designed by Mr. Lynn Thomas (*Brit. Med. Journ.*, 1904) (see Fig. 35) have one blade smooth and the other serrated, and have a catch by means of which they can be made to exert considerable pressure. The smooth blade is inserted through a small hole in the skin and pushed well beneath the vessel or vessels that it is desired to occlude temporarily. The serrated blade remains outside the limb, and any desired amount of compression can be exerted by clamping the handles together so that the vessel and the soft parts around it, together with the skin, are clamped between the blades of the forceps. It is however not essential to employ special forceps for this purpose as various forms of intestinal clamp-forceps answer the purpose admirably. The forceps should be thrust through the skin as high up as possible above the base of the flap; their pressure is relaxed and they are removed when the main vessels have been controlled.

These forceps seem to have a definite sphere of usefulness, and may well take their place as a necessary part of the surgeon's amputation outfit. They can be used when it is impossible to employ a rubber tourniquet, and they have the great advantage over the latter that there is no fear of their perishing from want of use, which is such a great drawback to Esmarch's bandage; they are also said to give rise to much less persistent oozing after removal, and that only from the skin.

Wyeth's Pins. Wyeth introduced the pins called by his name in order to widen the range of usefulness of Esmarch's rubber band, which they prevent from slipping when applied high up around the thigh, as

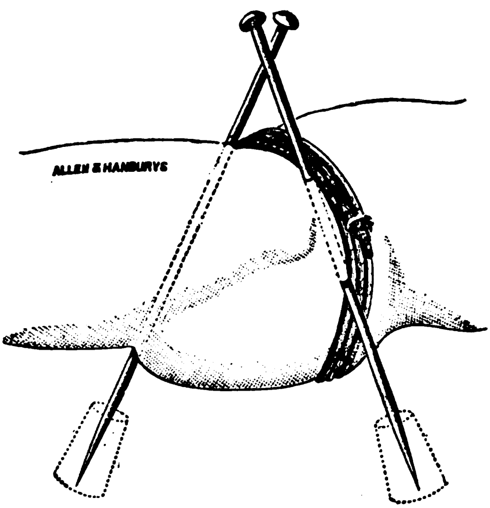

FIG. 36. WYETH'S PINS. On the outer side the tensor fasciæ femoris is transfixed by the stout pin shown in the drawing, the sharp end of which is guarded by rubber or cork. On the inner side most of the adductors may be transfixed so as to supply a firm basis of support which will prevent the circularly applied rubber band from slipping. It is usual in addition to apply a pad over the femoral and gluteal arteries beneath the rubber band.

for disarticulation at the hip-joint. They are stout steel pins or skewers which are made to transfix the soft parts, one on the outer and one on the inner side of the limb. Above the pins the rubber band is drawn around the limb as tightly as possible; the method is very similar to that of the transfixion pins used to prevent the écraseur from slipping in former days. The pins should transfix about three inches of the skin with the subjacent muscle, and should be long enough to project about three inches on either side, and stout enough to bear the strain of the rubber band above them without snapping. One end should be sharp, and the other furnished with some form of handle by which they can be driven through the skin. They should go well into the muscles, but should be applied at some part where no important structure is likely to be transfixed. It is quite immaterial on which side of the limb they are placed; the surgeon will be guided by the demands of the individual case. In a disarticulation at the hip the most convenient spots will be beneath the anterior superior spine, transfixing the tensor fasciæ femoris on the outer side and the adductor longus, just below the fold of the groin on the inner side (see Fig. 36).

It is important to remember that the divided vessels should be secured at the end of the first stage of the amputation before disarticulation is commenced, as otherwise the vessels may retract out of the way and bleed in spite of the tourniquet when the support given by the head of the bone has been lost.

Methods of fashioning flaps. The circular amputation. The circular method is the parent of all the amputations that have since been practised. It is obviously the quickest and simplest form, and when the soft parts are damaged up to the same level on the two sides of a limb it allows the bone to be sawn nearer to the area of damage than does any other; it is therefore very economical. The cut surface it leaves is smaller than that in any other amputation, and the blood supply of the flaps is good, all the vessels being cut at right angles to their long axis.

While this method had been largely abandoned before the war, the exigencies of profound infection, shock, and great debility have brought it into favourable notice again with this modification, that the amputation is performed without any attempt to suture over the end, this being left for subsequent attention. This so-called *Guillotine operation* Kelly says possesses sufficient advantages in severely infected cases to recommend it over the usual flap operations.

1. It lessens shock by (*a*) shortening the time of operation; (*b*) permitting amputation at the lowest possible level.

2. It decreases the danger from infection by (*a*) exposing the least possible extent of raw surface; (*b*) avoiding the impairment of the circulation incident to the formation of flaps.

3. It is also said to lessen the risk of secondary hæmorrhage.

Its indications are stated to be gaseous, gangrene, and certain cases of compound comminuted fracture and of multiple wounds.

The skin and deep fascia are divided, usually in circular fashion, but sometimes more skin may be gained by making the incision oblique; after retraction has occurred, the muscles are divided at the level of the retracted skin—not too quickly so as to allow a retraction of the layers;

then the bone is sawn flush with the muscle; vessels are secured and nerves carefully shortened.

If the operation has been properly performed, the surface is at first slightly concave, but soon becomes convex from further retraction. This must be overcome by extension.

When the incision is left open, whether the circular method has been used or the one with short flaps, traction should be applied to the skin as soon as the acute inflammation has subsided, to overcome retraction and thus limit the size of the resulting scar. If it has been possible to make flaps of sufficient size, the skin may be pulled down sufficiently to approximate the edges and in some cases a secondary suture may be performed; if the tissues are not sufficient to cover the bone, they are kept from retraction until it is safe to perform a secondary removal of the projecting bone or a typical reamputation.

Two methods of extension seem to meet all indications. Adhesive strips are applied to the stump in the axis of the limb as far as the joint above and held in place by a circular strip, or pieces of gauze are applied in a similar manner with the adhesive glue; the ends are fastened to a ring, which may be attached to a weight extension or to the end of a modified Thomas knee splint. The former is superior since it gives more powerful traction, allows more movement of the joint above, adjusts itself to the patient's movements, and the patient is more easily nursed.

If circular amputation be done as an operation of election in an uncomplicated case, a circular incision is carried through the soft parts down to the bone. These are then retracted for a sufficient distance and the bone sawn through.

The plan of dividing the soft parts so that a hollow cone is formed on the face of the stump (see p. 260) is a great improvement upon the older clumsy method, and should always be adopted, as otherwise it is very difficult to approximate the flaps properly, owing to the large mass of muscle divided. The circular method, however, has a disadvantage which prevents its use under certain circumstances; the cicatrix necessarily lies over the end of the bone, and therefore the method is out of the question for cases in which pressure has to be borne directly upon the end of the stump, as in many amputations in the lower extremity. Moreover, in a muscular limb it is difficult to retract the muscles sufficiently to secure proper exposure of the bone at the proposed point of division, and the flaps can seldom be brought together neatly; the stump is puckered and often becomes conical. On the other hand, the circular method is very useful in the upper extremity, where the length of limb that can be preserved is a matter of primary importance, and no pressure is thrown upon the end of the bone.

Amputation by an elliptical incision. This is the first development from the simple circular method and its evolution is due to various causes. It soon became evident that in amputations in the lower extremity it was necessary to place the scar well away from the end of the bone. By making the incision around the limb at an obtuse angle to its long axis instead of at right angles to it the incision is made to reach a lower point on one aspect of the limb than on the other, so that a single long flap was formed, which could be drawn over the end of the bone, and the cicatrix thus placed well out of the way of pressure. Moreover, when the soft parts are damaged higher up on one side of a limb than the other, a true circular amputation would involve an unnecessarily high division of bone, whereas an elliptical incision with its lowest point on the side on which the sound tissues extend the lowest allows the bone to be divided as low down as possible. Also, the amount of retraction of the skin and subcutaneous tissues varies in different parts of the limb, and it may require an elliptical instead of a circular incision to make the level of the incision on the two sides of the limb equal after this retraction has taken place.

Flap methods. From these two primary types, the circular and elliptical amputations, the modern flap methods have been evolved. Thus from the true circular method came the modified circular and the racket amputations, whilst from the elliptical incision was derived the oblique racket, the lanceolate incision of Kocher, and the amputations by unequal flaps. The primitive circular amputation was useful only in limbs circular in contour and containing a single bone, such as the thigh and the upper arm; in tapering limbs or those with two parallel bones extra incisions had to be added to the circular or elliptical ones, so as to enable the muscles to be retracted easily up to the desired bone level. Thus a single longitudinal incision added to the circular one gave the ordinary transverse racket incision, whilst two such vertical incisions on opposite sides of the limb gave rise to the equal flap method. Similarly, the addition of a single vertical cut to the elliptical incision gave the oblique racket, and by a later development the lanceolate incision (Kocher), whilst two vertical incisions gave the unequal flap method. In early days these flaps had square corners, but a further development, a sacrifice to neatness, was a rounding-off of the corners so that the U-shaped and semicircular flaps came into use.

The flap method possesses great advantages. Excellent and easy exposure of the bone at the point of section is obtained by it, and the surgeon can fashion his flaps from any region of the limb that he desires; while after the bone has been sawn, they come together easily. The disadvantages are not serious, and they only apply to amputations by unequal flaps. In them the bone has to be divided higher up than is absolutely necessary, except when the soft parts are damaged higher up the limb on one side than on the other. This, however, is rarely a point of great importance, but if it is, the method must be rejected in favour of the circular, if that method be available. A disadvantage of the flap method is that the blood-supply of the flaps, especially the longer one, is not so good as in a circular amputation. This is doubtless true, but, unless the length of the flap be extreme, as for instance in Teale's amputation, there is no risk of sloughing in an aseptic case. The surgeon, however, should bear this point in mind when amputating in regions or on subjects with impaired vascular supply, and should then adopt a method that is not open to this objection.

When planning his flaps the surgeon must remember that, after division, various circumstances influence the amount of retraction of the soft parts, especially the muscles. The muscles which are free between their points of origin and attachment, such as the biceps, hamstrings, &c., contract most; those which have a wide bony origin contract least. The flexors generally contract much more than the extensors, and allowance must be made accordingly in cutting them; thus, when amputating through the lower third of the thigh the muscles are cut much more directly to the bone on the flexor than on the extensor surface. The more muscular the subject, the more marked is the retraction; and, conversely, the minimum amount of retraction is met with in atrophied or inflamed muscles. After amputation the muscles thrown out of use undergo almost complete atrophy, becoming converted into a mass of fibrous tissue. Muscular contraction should come to a standstill soon after the operation; any further shortening is due to inflammatory contraction.

The retraction of the skin is considerable, and, like that of the muscles, varies in different parts of the body, and under different conditions. It is least where the subcutaneous tissue is scanty and the skin is thin and has deep connexions with the subjacent bones or aponeuroses. Thus, in the neighbourhood of the knee-joint the retraction is comparatively slight, as it also is when there is inflammation or œdema of the soft parts. Speaking generally, the retraction of the skin is more marked the nearer the line of amputation is to the trunk, and the average shrinkage is about one-third of the length of the flap. It must be remembered that in the dead body the retraction of the skin is much less than in the living subject, and in the bodies prepared with formalin for dissecting-room purposes there is practically no retraction at all.

Factors influencing the surgeon's choice of methods. The first essential in selecting a method of amputation is to see that it provides the most useful stump possible. The next is to choose one that will do this with the least possible sacrifice of healthy tissue. The longer the stump the more satisfactory it is to the patient, and as a rule the more easily fitted by the instrument-maker, and therefore all so-called 'expensive amputations', such as Teale's, which involve division of the bone at a higher level than is absolutely necessary, are to be avoided. Hardly inferior in importance to these points is the necessity for securing for the end of the stump ample covering provided from parts suited for bearing pressure, and a healthy, narrow, and sound scar so placed that it is not exposed to irritation. The last important point influencing the surgeon's choice is that the flaps must have an ample blood-supply. This becomes a factor of great importance in elderly persons, or those subject to arterial disease; in them it may be necessary to amputate through the knee or even higher for a small patch of gangrene in the foot solely because of the inadequate blood-supply below this point.

Other minor factors may influence the surgeon's choice, but they are much less important now than formerly. Rapidity in operating was at one time esteemed greatly, but this factor is now taken into consideration only in cases that are likely to be accompanied by severe shock; in them rapidity of operation is important, as it is an essential factor in the prevention of shock. Rapidity has now given way to methodical and careful fashioning of flaps, followed by accurate approximation. Other things being equal, the surgeon will of course always choose the method which is easiest of performance, and which allows him to expose and divide the bone with the least inconvenience and expenditure of trouble.

Methods of raising the flaps. Marking out and raising the flaps was formerly always performed with the old-fashioned amputating knife; now it is generally done with a large scalpel. Formerly the flaps were largely cut by transfixion, and this necessitated the use of the long knives so often found in amputation cases, which have blades at least one and a half times the length of the transverse diameter of the limb they are intended for use upon. Save in a few exceptional cases that will be mentioned later, the long and clumsy amputating knives have entirely gone out of use. The modern surgeon performs practically all the major amputations with a knife not larger than an ordinary breast knife; indeed for the majority an ordinary scalpel suffices. Occasionally special knives are required; for example, amputation of the terminal phalanges of the fingers by a long palmar flap is done by means of the so-called 'finger knife', viz. a bistoury about three inches long with a very narrow blade in order to allow the knife to be turned at right angles after it has passed through the inter-phalangeal joint. The circular amputation also requires a special knife of considerable length; it has a rounded end and its cutting edge is slightly concave so as to bring as large an extent of it as possible into contact with the structures to be

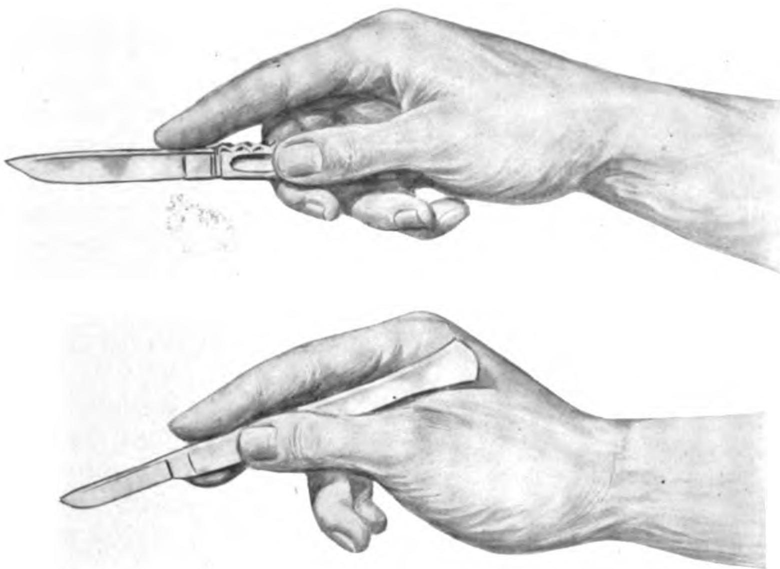

FIG. 37. METHODS OF HOLDING THE AMPUTATING KNIFE. The upper figure shows how the knife should be held when marking out the skin incision. If held in this way, the operator has perfect control over the blade, which should be made to trace out the incision while the knife is held nearly horizontal, as shown in the figure. This brings the whole of its edge to bear upon the skin and makes an easy and smooth incision. The lower figure shows the manner in which the knife is held for fine dissecting work. This is a wrong manner in which to hold the knife during amputations, as the greater delicacy of manipulation that it ensures is obtained at a great sacrifice of power.

divided. For all other purposes the ordinary scalpel, a breast knife, or, when flaps have to be raised from bone as in Syme's amputation.

How to hold the knife. In an amputation the knife should always be held as shown in Fig. 37 except when a circular amputation is being performed; then the knife is held as in Fig. 38. Both these methods of holding the knife give the maximum amount of control over the blade and point. The blade of the knife should always be kept at right angles to the surface that is being divided; if it be inclined at an angle the tissues are undercut, and the vitality of the flaps may be interfered with by wounding the vessels supplying them. The knife should be made to cut with the belly and not with the point only; a common mistake with beginners is to mark out the flaps with the point of the knife only, and the result of this is to throw the skin into folds in front of the knife, so that an ugly irregular incision results. The most satisfactory way of cutting a flap is to plunge the point of the knife into the skin at the commencement of the incision, and then to depress the handle until nearly the whole of the cutting edge is in contact with the skin, when the knife is made to trace out the flap by drawing it along with a gentle sawing movement, employing nearly the whole of the belly of the knife in the process.

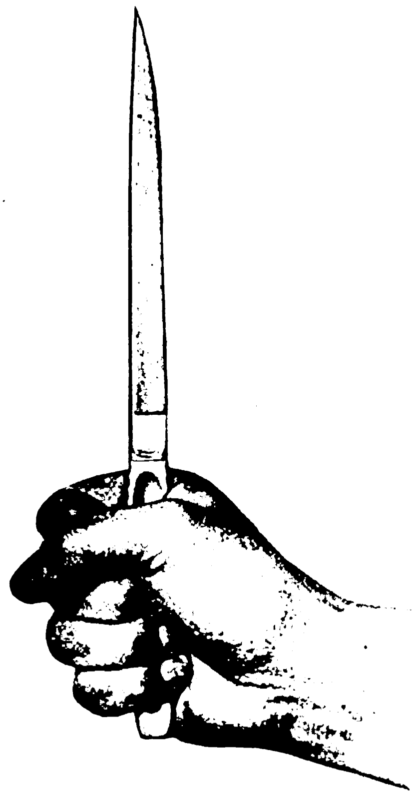

FIG. 38. METHOD OF HOLDING AMPUTATING KNIFE WHEN MAKING CIRCULAR INCISIONS. The knife is held thus when performing a circular amputation or dividing muscles by a circular sweep. It enables the knife to be carried as far as possible round the limb and at the same time gives the operator perfect control over it.

When performing a circular amputation, the knife is drawn steadily round the limb from heel to tip, and should not be made to cut the incision with one portion of its edge only, as is often done. By doing it correctly no undue pressure is thrown upon the soft parts, which are consequently evenly divided without displacement or irregularity.

When disarticulating, only the point of the knife should be used to divide the various ligaments connecting the bones; owing to the irregular outline of the joint surfaces, the knife is often much hampered in its movements if more than the point be employed.

Flaps are only cut by transfixion when many tendons have to be divided. The reason for this is that these structures are difficult to cut from without inwards, as they retract unequally and roll under the knife; in order to secure a neat and uniform line of section, therefore, they are best divided in one mass by introducing the knife between the bone and the tendons, and cutting through them by a quick upward

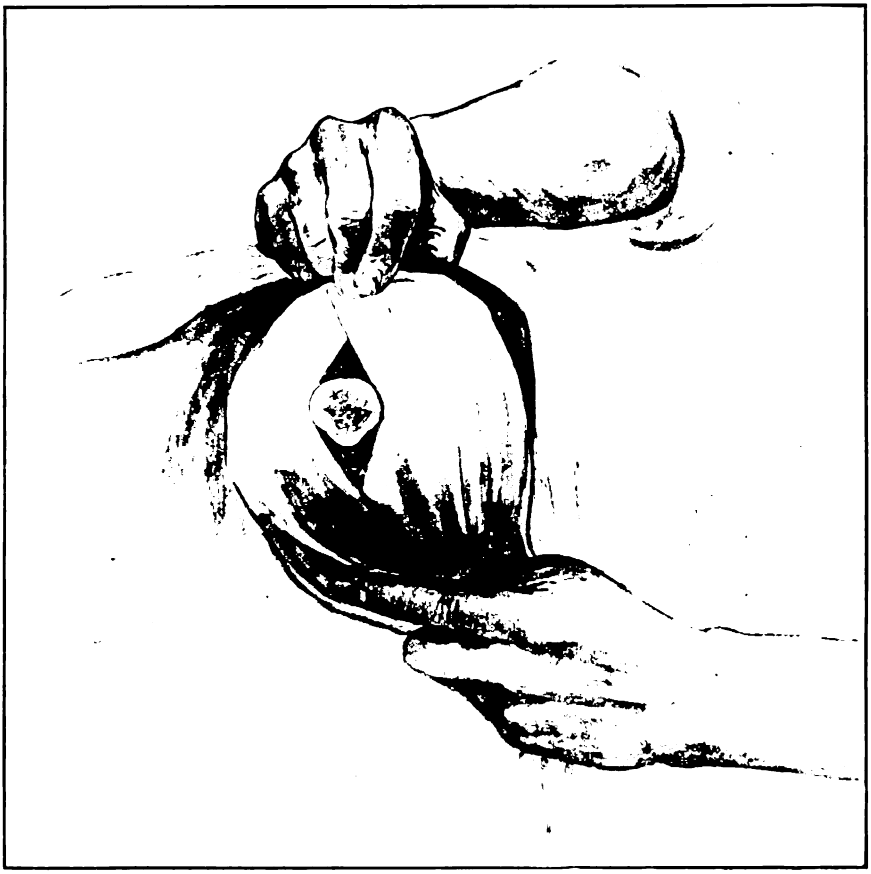

FIG. 39. METHOD OF APPLYING A TWO-TAILED LINEN RETRACTOR. The figure shows how the two tails of the bandage cross one another in order to retract the soft parts and leave the bone exposed. The two tails are crossed under the assistant's upper hand as shown in the figure.

sawing movement. Formerly the entire flap was often cut by transfixion, the knife being entered through the skin, thrust across the limb between the bones and the soft parts on a level with the line of bone section, and the flaps of skin and muscle cut by carrying the knife down with a sawing movement a certain distance, and then cutting straight out. Nowadays the skin flap is never cut by transfixion, except in amputations of the terminal phalanx of the fingers by a long palmar flap: when transfixion is employed, as in the lower third of the forearm and

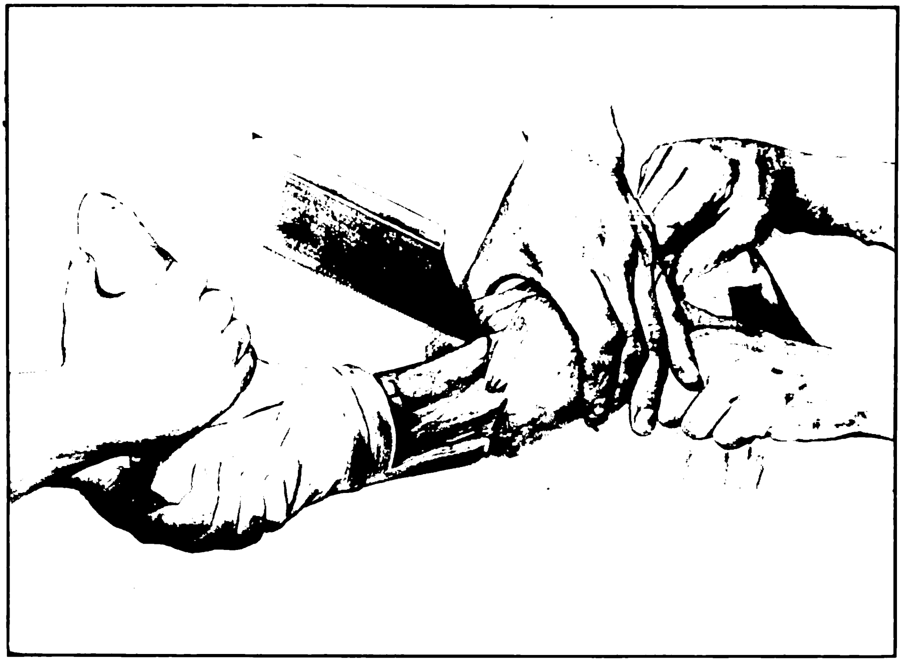

FIG. 40. APPLICATION OF A THREE-TAILED LINEN RETRACTOR. The three tails of the bandage can be traced in the figure. Of these the middle passes through the interosseous membrane and is partially covered by the two lateral tails, which keep back the soft parts from the tibia and fibula.

the thigh, the skin flap is marked out first and its edges allowed to retract, and the tendons are cut by transfixion subsequently.

Retractors. After the flaps have been cut and dissected up sufficiently the bone is sawn. In order to protect the flaps from damage by the saw while the bone is being divided, they must be held back by suitable retractors. Retractors of many kinds have been introduced, but there are few so satisfactory as the two or three-tailed linen bandage, used for amputations where there are a single or two parallel bones respectively. Figs. 39 and 40 show how these are employed.

Division of the bone. This is generally done with a saw; cutting-pliers should be avoided, as they crush the bone to some extent, while chisels are very clumsy implements for this purpose. An ordinary tenon saw of suitable size is the most useful kind. The blade should be at least an inch wider than the bone that has to be divided; otherwise the saw must have a movable back. The tenon saw is easy to handle, and cuts a clean level surface. Other saws, such as Butcher's, the metacarpal saw, &c., are only needed under special circumstances; Butcher's saw is very useful when a convex or concave surface has to be cut.

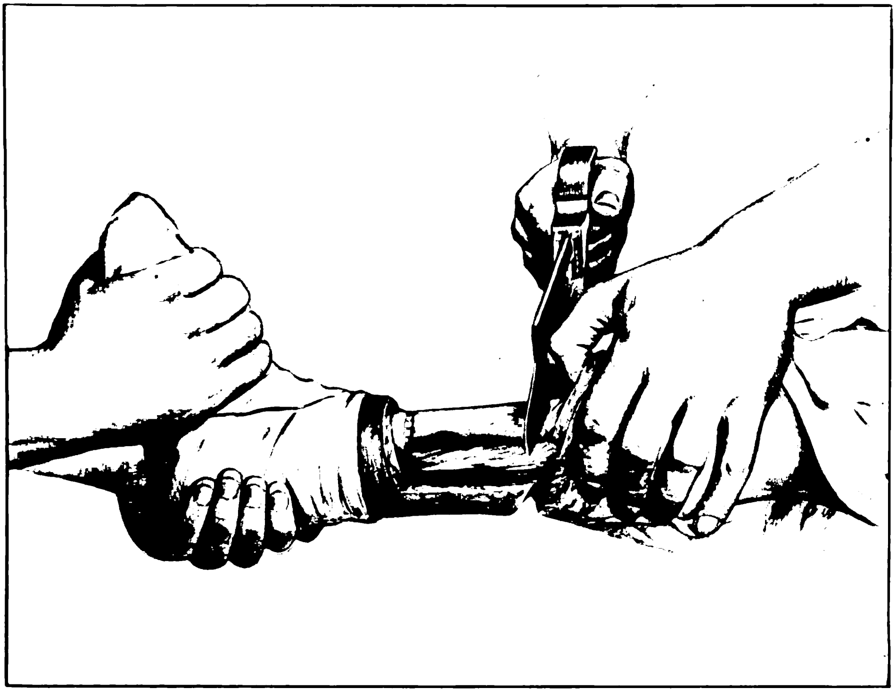

FIG. 41. STEADYING THE SAW WHEN DIVIDING A BONE. The surgeon's left thumb in the position shown in the figure forms a firm buttress against which the saw can be rested without any risk of the latter slipping upwards. If the thumb be bent in the particular manner shown in the figure it is impossible to damage it with the saw.

Gigli's wire saw is very useful for dividing the lower jaw, and also in removal of the superior maxilla.

When the bone is being divided the saw should be first drawn lightly from heel to point several times across it, in order to cut a groove for it to work in; Fig. 41 shows how the saw is steadied by means of the left thumb while this is being done. The limb is grasped in the left hand above the line of division, and an assistant holds the distal end firmly and quite horizontal while the surgeon divides the bone with rapid light strokes; undue pressure must be avoided, as it helps to lock the saw and to break the bone. The assistant must not raise the limb, or the saw will be locked, nor depress it too forcibly, or the bone will be fractured prematurely. With care it is easy to saw the bone cleanly through without leaving spicules on the cut end; if any be left, however, they can be clipped away with suitable cutting-

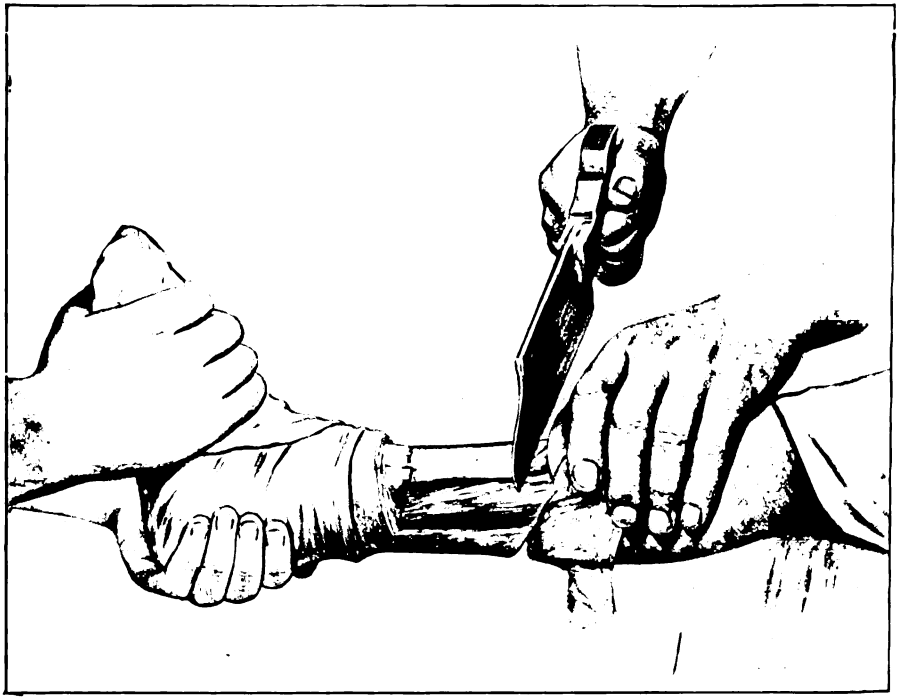

FIG. 42. BEVELLING OFF THE BONE IN AMPUTATIONS. Examination of the figure will show that the oblique cut has already been made and the saw is in the act of making the transverse section of the bone. As the transverse section meets the oblique one a small triangular piece of bone is dislodged, and when the bone has been entirely divided its sharp margin is found to be bevelled off.

pliers. A bone should always be divided with a saw, and not with cutting-pliers; however sharp and powerful the latter may be, they tend to split the bone to some extent instead of dividing it cleanly as a saw does.

In certain cases the end of the bone has a tendency to protrude beneath one of the flaps, and, if it possesses a sharp edge, this may become adherent to or actually ulcerate through the flap. To avoid this it is usual to bevel off any sharp edges of the bone, especially in the case of the tibia, and Fig. 42 shows how this is done. The oblique cut to remove the sharp edge is made first, and is carried through about a third of the thickness of the bone; the transverse incision to remove the limb is then made, and the distal portion of the bone and the small bevelled-off portion come away together.

The arrest of hæmorrhage and closure of the wound. When the bone has been sawn and the limb removed, the flaps are held wide apart, and the main vessels are identified and secured with pressure forceps. Large vessels, such as the femoral or brachial, should be pulled well out of their sheaths by dissecting forceps and the pressure forceps applied transversely to their long axes; otherwise, only part of their circumference may be caught, and dangerous bleeding may follow removal of the tourniquet. Moreover, this plan obviates all danger of including the companion nerves in the ligature—an exceedingly unpleasant complication. The main veins are thus temporarily secured as well as the arteries. Immediately before the tourniquet is removed it is well to pack swabs or sponges tightly between the flaps, so as to keep down the bleeding when the pressure is taken off, and allow the surgeon to pick up the bleeding points *scriatim,* first in one flap and then in the other. The oozing following removal of the tourniquet is usually free, particularly from the cut muscles, and may last for some time; it is best controlled either by douching the surface with sterilized water at a temperature of 115° F., or, in weakly subjects, by the application of a sterilized solution of adrenalin. All oozing points are caught up in clamp forceps without waiting to tie any of them, and to facilitate this the limb must be held well up and the flaps fully displayed by an assistant. After all the definitely bleeding points have been secured thus, the wound is douched with hot water and ligatures are applied; these should be of medium thickness for the main vessels, but of the smallest size for the others.

In this manner the bleeding can be usually controlled satisfactorily, with the possible exception of that from the bone, which may cause much inconvenience, especially if the bone has been divided near the nutrient artery. Should there be unduly free bleeding from any particular portion, an attempt may be made to stop it by crushing up the bony tissue from which the bleeding comes with a blunt bradawl or a steel director; failing this, Horsley's wax forced into the cut bony surface will be successful.

The more cleanly the parts are cut and the less the flaps are handled the better is the result likely to be, and in arresting hæmorrhage particular care must be taken that the cut surfaces are not infected by accidental contact with non-sterilized portions of clothing, &c., as the surgeon and his assistant lean over the stump.

Drainage should be provided in every amputation except the small ones, such as the fingers. Oozing after the operation is inevitable, partly as a result of the use of the tourniquet, partly from the irregular contraction of the divided muscles which always occurs after amputation; this renders it impossible to approximate the soft parts so accurately that there shall be no space left in which blood can collect. A drainage tube is therefore essential to avoid the risk of the flaps being separated by clots and giving way subsequently. The tube should be large, so that it may carry off the blood rapidly; it should be inserted at the most dependent spot. It is best not to carry it across from one angle of the flaps to the other; should it be deemed advisable to drain both sides of the stump, this should be done by separate tubes.

The flaps are brought together by *sutures,* which are inserted so as to approximate the deeper tissues, as well as the edges of the skin. Sutures of silkworm-gut or stout silk should be inserted at some distance from the edge of the stump, so as to bring the opposing surfaces of the flaps equally into contact throughout; buried sutures of catgut may also be used if desired. The approximation is completed by a continuous suture which brings the skin edges into accurate apposition everywhere. There are few more important predisposing causes of sepsis than badly approximated flaps, as infection easily reaches the interior of the stump from raw areas on its surface.

The drainage tube should be sutured to the flaps, as otherwise it may be pulled out of or pushed into the stump. It should be removed within three days, and, at the time of the operation, it is a good plan to insert a suture at the spot at which the drainage tube is, and to knot it loosely in a loop instead of tying it; this can be tied when the drainage tube is removed, and thus the interior of the stump is protected from the risk of contamination. When there is much pain following the operation, and a dressing for removal of the tube on the third day would distress the patient, the tube may quite well be left *in situ* for some days longer.

The method of immobilizing the limb after the operation is of importance, as the patient's comfort depends largely upon the absence of spasmodic contractions of the muscles of the stump. In order to prevent this it has long been the custom to apply the bandage fastening on the dressings in a circular manner round the limb, and to carry it from above downwards instead of from below upwards. This exerts uniform compression upon the muscles and tends to steady them. A splint or splints should always be applied, as otherwise a good deal of starting pain is likely to be experienced.

The future of the stump. No amputation can be looked upon as really successful unless it leaves the patient with a perfectly sound, painless, well-nourished stump which can be fitted with an artificial limb that will restore the functions of the lost extremity to the greatest extent possible, and the amputation should not be performed unless the surgeon has clearly in his mind the form of stump that he wishes to produce. The after-history of the amputation should be uneventful, as, if the amputation has been carried out above the level of the disease for which it was performed, and through tissues with an efficient vascular and nerve supply, healing by primary union should occur throughout. The deep sutures can be removed in about a fortnight's time, and the superficial ones a week later. The period of time that must elapse before a patient can bear his weight upon the limb will vary with the particular amputation, but speaking generally it will be from a month to six weeks.

END-BEARING STUMPS

In preparation for the exigencies of war surgery, the Surgeon General's office, U. S. A., has summarized our present knowledge concerning this important subject and outlined the following system of treatment, drawing attention to the fact that with the exception of the Symes and Gritti-Stokes amputations, the usefulness of which is well known, little attention has been given to this subject. With these exceptions artificial legs are designed by the makers to take the weight on the ischial tuberosity when the amputation is above the knee, and laterally on the tuberosities of the tibia when it is below, and little or no attempt at end-bearing is made. The possibility of securing an end-bearing stump in a large proportion of cases has, however, been clearly demonstrated, and it is highly desirable that the surgeon and the artificial limb-maker should coöperate to achieve it; for it is obvious that the transference of even a part of the weight to the end of the stump will conduce to greater comfort and improved function.

The chief responsibility rests, however, upon the surgeon, since the prerequisites for end-bearing are a good stump and early functional use.

Hirsch, Lyle, and others have outlined a routine stump treatment designed to secure the maximum result in such cases. Muscular weakness and limitation of motion are two of the chief causes of discouragement in learning the use of artificial limbs.

To meet all indications the plan of treatment must be systematic.

While the incision is healing, at each dressing the stump should be moved to the full limit in the opposite direction to that in which a contracture is likely to develop. In forearm stumps, movement should be carried out in supination and extension; in upper-arm amputations, in upward and backward motion; in the lower leg, in extension and in thigh amputations, in extension (securing hyperextension) and adduction. It is usually advisable to keep all stumps elevated while the patient is recumbent and therefore particular attention should be directed to thigh amputations because this position favours a flexion contracture; to counteract this tendency it is recommended that once or twice each day the pillow be removed from under the stump and placed under the buttock, thus allowing the stump to drop into hyperextension. Further, advantage should be taken of the position in which the stump is dressed in order to guard against the tendency to contracture; thus in forearm stumps, where supination is hardest to control, the dressing should be applied so as to maintain the bones in this position. When the incision has had to be left open movement of the joint in the other directions, also, should be added as soon as conditions permit.

As soon as the wound is healed, or practically so, and while the patient is still confined to bed, the following routine (modified from Hirsch) is begun:

1. *Massage.* The stump should be massaged for a period varying from ten to thirty minutes, once or twice a day, according to its size and position. The region of the incision should naturally be avoided for the first few times and care taken not to make undue tension on the fresh scar. As rapidly as the tolerance of the stump will permit, the depth and the force of the massage should be increased up to the full normal limits.

2. *Bandaging.* After the massage, the stump should be redressed with a cotton dressing, bandaged snugly in place, or if it is well healed, a bias flannel bandage alone may be used. The latter, when properly applied in several layers, gives a firm, even pressure.

3. *Pressure Exercise.* The patient is directed to press the end of the bandaged stump against a cushion, placed in the bed or against a frame. This must be begun with care, pressure being made at first for only several minutes at four- or five-hour intervals; if there is no unfavourable reaction, it should be increased gradually up to five or ten minutes every two hours and then every hour.

4. *Movements.* After each pressure exercise, active movements of the stump are to be made in all directions, to the full limits of the joint motion, for three to five minutes. Later, some form of resistance movements may be added to advantage, in order to still further build up the

strength of the muscles controlling the stump and so make the early use of the artificial limb more easy.

5. *Baths, etc.* Hydrotherapy in the form of hot packs or warm and cold baths alternately, or electric light baths are to be used as indicated to improve the circulation and hasten absorption.

When the patient is able to leave the bed, the measures just outlined are to be continued, but in the case of leg amputations the pressure exercise is to be discontinued as described and direct weight-bearing on the stump begun. A stool of the proper height and a cushion are provided and the patient, supporting himself with his hands, allows at first only a little weight to rest upon the bandaged stump; the amount of weight borne and the time are then gradually increased, in a manner similar to that used in the pressure exercise in bed, until the entire weight can be taken on the stump. As soon as the patient can stand alone for a long time without getting tired, and with no other support than that needed to balance himself, a temporary leg, properly provided for end-bearing may be fitted and walking begun, crutches being used guardedly and dispensed with as soon as possible. For a long time, however, the patient should continue to practise standing on the bare stump on a hard surface three times a day.

The value of end-bearing is generally admitted. The measures suggested, both with respect to the amputation and the care of the stump, are simple and have borne the test of clinical experience. Their persistent use is urged upon all. While it is recognized that in very many cases the presence of long-continued infection will seriously delay the institution of proper after-treatment, yet much good may still be expected even when begun late, and there will be a large number in which the routine may be followed from the first.

The joint motion should be tested by the surgeon at regular intervals, particularly in bed-ridden infected cases, in order to be certain that the full range is retained. At the elbow, in addition to verifying the presence of complete flexion and extension, the freedom of rotation of the radial head must be determined and particularly with reference to outward rotation (supination); the value of the movements of pro- and supination in activating the artificial hand will depend upon the degree possible, the loss of even a few degrees making a great difference. Of the movements of the shoulder girdle (upward, downward, forward, backward, and circumduction), the upward and backward ones are the most important; these may be easily tested with the patient lying at the edge of the bed or turned on the opposite side. At the knee it is well to remember that there are normally a few degrees of recurvation. In testing the hip, the presence or absence of flexion deformity may be determined (following the method used in hip disease) by flexing the opposite thigh fully on the trunk, the stump rising from the bed when a contracture exists, or with the patient lying on the face, the degree of hyperextension may be determined (again as in the similar test used in hip disease) by lifting the stump with one hand while holding down the buttock with the other; in testing the amount of adduction, movement of the pelvis should be controlled with one hand while the other manipulates the stump.

Mortality. It must always be difficult to estimate the mortality of any given form of amputation, as the operations are done for such widely diverse conditions. If, however, amputations be divided into those performed for cases in which there is septic infection and those in which there is none, the mortality of the latter group should consist of only those cases in which death is due directly to the severity of the operation or to the presence of some intercurrent disease. This risk is greater in the old than in the young, and is much increased when it is done for accident, probably because the shock of the accident is added to the shock of the operation. We are still in need of carefully compiled statistics of the various forms of amputation performed with full aseptic precautions. It is probable that the mortality of all except amputations high up in the thigh, disarticulations at the hip and shoulder joints, and Berger's 'fore-quarter' amputation, will prove to be practically ***nil,*** while of the other forms mentioned, the statistics quoted by Hasbrouck (*Surg. Gyn. & Obstet.*, vol. vi, p. 289) as the mortality of Berger's interscapulo-thoracic amputation may be taken as a fair sample. He quotes Schultz as giving the death-rate for 1875–96 as 13.04%. Berger gives 5%, and Fowler (1900) gives 11.1%. Douglas for 1887–1906 gives the rate as 7.84% for 153 cases, which should be a fair average. The previous figures embrace many cases done under faulty aseptic technique.

AMPUTATIONS IN THE UPPER EXTREMITY

CHAPTER II

AMPUTATIONS OF THE HAND AND WRIST

AMPUTATIONS OF THE FINGERS

THE rule that as much of the limb as possible should be preserved is of special importance in the cases of the fingers. The smallest portion of a finger that can be saved is of value to the patient, and therefore an irregular operation suitable to the particular needs of the individual will often be chosen in preference to any set amputation.

Surgical Anatomy. Certain points must be borne in mind in all these amputations. In the first place, a knowledge of the level of the inter-phalangeal joints is important, as the operation of disarticulating is much facilitated thereby. The prominences of the finger-joints are formed, not by the bases of the distal, but by the heads of the proximal phalanges, and the levels of the joints are one-twelfth, one-sixth, and one-third of an inch respectively below these prominences, counting from the last inter-phalangeal joint upwards to the metacarpo-phalangeal articulation.

In the second place, the arrangement of the tendons in long rigid tendon sheaths, which gape widely after section, must be remembered. This is not a matter of importance in the ordinary aseptic operations done for recent injury or for growth, but it becomes important when the amputation is performed for suppurative affections, such as whitlow or an old injury. Sepsis can spread with great rapidity along the open tendon sheaths into the palm and above the wrist after an operation through infected tissues, and proper precautions must be taken to guard against its doing so.

The mode of attachment of the flexor tendons has an important bearing upon the usefulness of the stump resulting from the amputation. The flexor profundus sends back accessory ligamentous bands which are attached to the middle phalanx, nearly as far up as its centre, and therefore this attachment is retained when the amputation is performed below that spot, and a useful movable stump results. When, however, the amputation is done above this point, neither the flexor nor the extensor tendons have any attachment to the phalanx, and they retract for some distance up their sheath when they are divided, so that the stump of the finger is rendered useless. When amputating above the centre of the middle phalanx, therefore, the flexor tendons should be seized in forceps before they are divided, and cut as long as possible; the divided ends can then either be brought across the end of the bone and sutured to the extensor tendon, which is treated in a similar manner, or sutured to the edge of the sheath or the soft parts in its immediate vicinity. If this precaution be taken, the old rule, that amputation should not be performed between the centre of the middle phalanx and the metacarpo-phalangeal articulation for fear of obtaining a useless stump, may be safely discarded in favour of the more useful rule of retaining as much of the finger as possible.

An important practical point in connexion with all amputations of the fingers is that the cicatrix should be properly situated. After these amputations the pressure falls partly upon the palmar surface and partly upon the extreme end of the stump, and therefore the scar should

FIG. 43. FINGER BISTOURY. The blade is very narrow in proportion to its length and the cutting edge is horizontal.

never lie in either of these regions; consequently the amputation should be always performed by unequal flaps, preferably antero-posterior ones, the palmar being the longer; the cicatrix will then fall well above the mid-point of the end of the stump. A cicatrix exposed to pressure is a very troublesome matter in the finger.

DISARTICULATION AT THE TERMINAL INTER-PHALANGEAL JOINT

This amputation should always be performed by means of a single palmar flap, which gives a firm covering, preserves good tactile sensation, and places the scar well on the dorsal aspect of the finger. It is frequently required for a crush of the finger, and it is more difficult to perform neatly and quickly than a description of it would lead one to think.

The disarticulation is performed with a narrow-bladed bistoury, called a 'finger knife' (see Fig. 43), the special features of which are that its blade is narrow in comparison with its length, and has not a belly as a scalpel has. This particular form is to enable the knife to be turned easily behind the base of the phalanx when cutting the palmar flap. In length the knife should be about three times the breadth of the finger to be operated upon.

Operation. An assistant pulls the adjacent fingers as widely apart as possible with strips of bandage (see Fig. 44), and the surgeon, placing the pulp of his left index finger upon the palmar surface and his left thumb upon the tip of the nail of the finger to be operated upon, flexes the joint to a right angle, and then cuts into the inter-phalangeal articulation by drawing the knife across the extensor surface one-twelfth of an inch

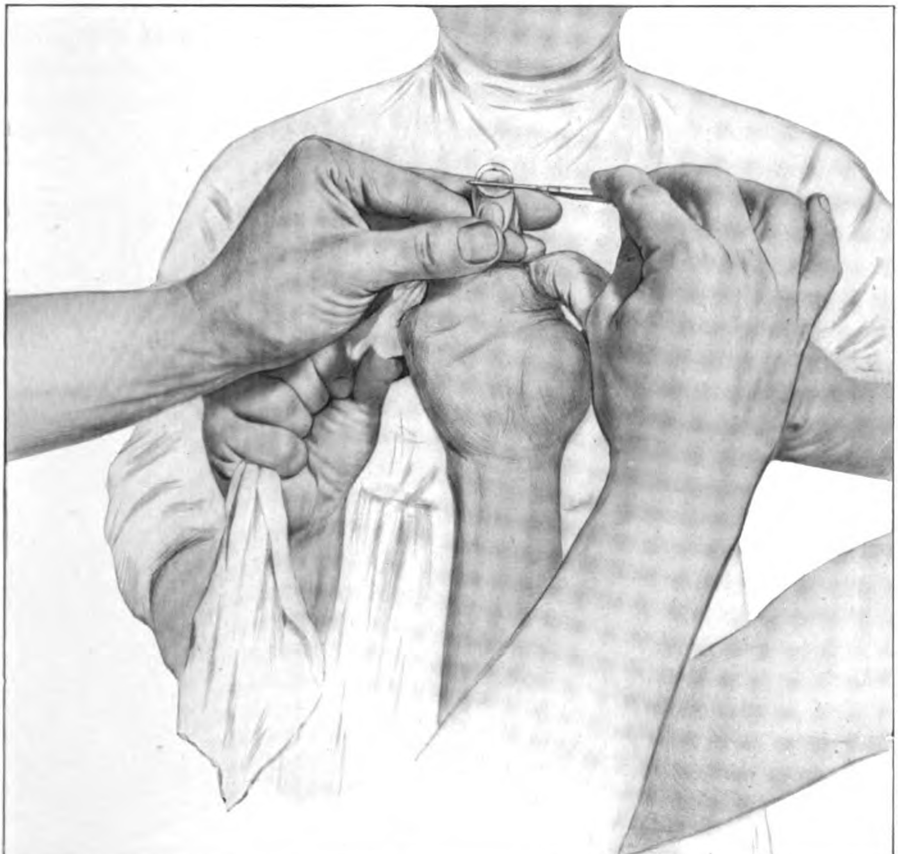

FIG. 44. AMPUTATION AT THE TERMINAL INTER-PHALANGEAL JOINT BY THE LONG PALMAR FLAP. *Making the dorsal incision.* The fingers are held out of the way with bandages by the assistant, who stands behind. The figure shows how the surgeon grasps the tip of the finger and opens the joint. For the sake of clearness the surgeon's hands have been figured as much to one side as possible.

below the prominence formed by the joint (see Fig. 44). In doing this the knife should be held strictly at right angles to the surface of the skin, as otherwise this will be bevelled and its extreme edge may slough. The first incision should divide the extensor tendon and open the joint; the usual mistake is to cut above the line of the joint when trying to do this.

The finger is flexed still further, and the knife divides the lateral ligaments by light movements from side to side without being withdrawn from the wound. The base of the terminal phalanx is then pushed firmly forwards by the surgeon's left index finger behind it, and the knife is carried across the joint, dividing the glenoid ligament and the insertion of the flexor digitorum profundus. When the anterior margin of the base of the phalanx is reached, the blade of the knife,

FIG. 45. AMPUTATION AT THE TERMINAL INTER-PHALANGEAL JOINT BY THE LONG PALMAR FLAP. *Completing the palmar incision.* The figure is intended to show how the surgeon holds the terminal phalanx when he finishes cutting the palmar flap so as to avoid wounding his own fingers.

which has hitherto been kept horizontal, is turned so that it is parallel to the palmar surface of the terminal phalanx, down which it is carried by gentle sawing movements until it reaches the point at which the finger begins to taper to its end; this is nearly on a level with the base of the free edge of the nail. The knife is now turned sharply at right angles to its previous direction, and cuts through to the palmar surface with one sawing sweep. As the knife cuts the end of the flap the phalanx is grasped between the thumb and forefinger by its base and tip (see Fig. 45), so as to avoid the risk of the surgeon wounding his own index finger when the knife is made to cut out. The whole operation should be done without removing the knife from the incision.

This operation fashions a rectangular flap containing all the palmar structures, and of ample length to envelop the head of the middle phalanx and place the cicatrix just on the dorsal aspect of the finger. No tourniquet is needed, and as a rule it is not necessary to ligature any vessels, as only the terminations of the digital arteries are divided, and

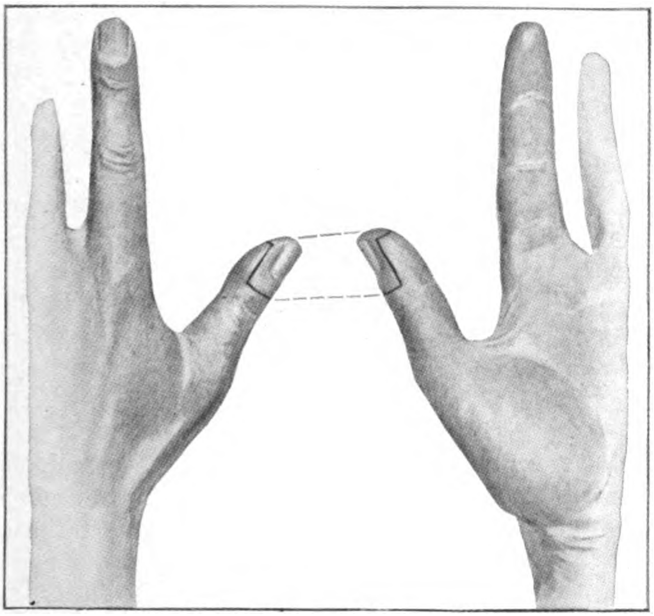

FIG. 46. AMPUTATION OF THE TIP OF THE THUMB BY A LONG PALMAR FLAP. The drawing shows the distance down the thumb in relation to the nail that the palmar incision extends.

the bleeding stops readily on pressure. Two deep sutures of silk or silkworm-gut are required to keep the heavy flap in position, and these may be reinforced by more superficial sutures if necessary. The dressing should be brought round over the end of the stump from the palmar to the dorsal surface. A small splint is put on to steady the finger and to fix the wrist and finger joints. No drainage tube is required, and the articular surface of the head of the middle phalanx need not be interfered with.

This is also a most excellent amputation in the case of the thumb (see Fig. 46), as it gives a stump full of tactile sensation and capable of bearing pressure well.

AMPUTATION THROUGH ONE OF THE PHALANGES

This may be done by a *single long palmar flap,* which, however, should not be cut as in the preceding operation. It is marked out by carrying an incision vertically down the middle of each lateral surface of the finger, far enough to give a flap of sufficient length; the lower ends of these incisions are joined by a transverse cut across the palmar surface of the finger, and the flap thus marked out is raised, the flexor tendons being divided on a level with the lower edge of the flap after having been secured by catch-forceps to prevent them from retracting up their sheath. The upper ends of the two lateral incisions are then joined by a transverse cut across the dorsum, and the bone is cleared and divided with a fine saw, at or just above this level.

By performing this amputation by *antero-posterior flaps,* the anterior or palmar flap being about three times as long as the dorsal, the bone can be divided relatively lower down. This gives a good stump with the cicatrix placed transversely just below the dorsal aspect of the bone.

In all amputations of the fingers above the centre of the middle phalanx the practice of uniting the cut flexor tendons, either to the extensor or to the soft parts in the region of the divided end of the bone, must be adhered to if the patient is to have a useful movable stump; this is a point of the highest importance, the neglect of which will vitiate an otherwise excellent result.

Numerous other forms of amputation have been adopted. Concerning them it may be remarked that those by equal antero-posterior or *lateral flaps* both possess the serious objection that the cicatrix is terminal, and therefore the patient must carefully avoid pressure upon it—a difficult matter in the case of the fingers. Similarly, amputation by *a large internal or external flap* is not perfectly satisfactory, as some part of the resulting cicatrix must be upon the palmar surface and therefore exposed to pressure. Amputation by *a single dorsal flap* is practically out of the question, partly because of the difficulty of fashioning a satisfactory one, and partly because the covering resulting from it is not calculated to stand pressure well.

DISARTICULATION AT THE METACARPO-PHALANGEAL ARTICULATIONS

A large number of amputations have been practised in this situation, the more important types of which, namely, the circular and the oblique racket and the elliptical incisions, and the single large lateral flap, are illustrated in Fig. 47. The cases for which each variety is most suitable will be indicated when each particular operation is described.

Surgical Anatomy. There are certain points to be remembered in connexion with all amputations in this situation. There is not the same objection to a terminal cicatrix in these operations as there is in the case of the fingers. After an amputation of the middle and ring fingers, the pressure falls upon the palmar surface, and the head of the bone is so protected by the adjacent metacarpals that it is not exposed to direct pressure; therefore the cicatrix may safely be terminal, and

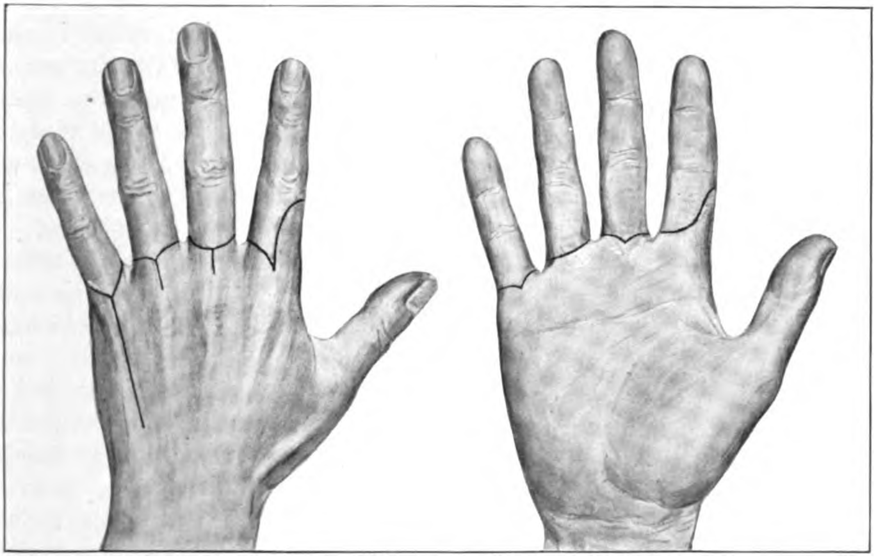

FIG. 47. AMPUTATIONS AT THE METACARPO-PHALANGEAL ARTICULATIONS. The amputation of the index finger is Farabeuf's large radical flap; that of the middle is the ordinary transverse circular racket; that of the ring finger is similar to the middle, except that it shows the method of slightly rounding off the flaps to make the cicatrix more sightly (by an oversight the corresponding palmar portions of these incisions have been transposed; that on the middle finger should be on the ring finger and *vice versa*). The amputation of the little finger is the oblique racket and is meant for use when the head of the metacarpal bone is removed with the finger.

indeed is so in the most popular forms of this operation. There are, however, three situations in which a terminal cicatrix may be of disadvantage to the patient; they are the thumb, the index and the little finger joints. In the thumb the pressure falls upon the palmar and the radial aspects of the head of the metacarpal, and disarticulation at the first metacarpo-phalangeal joint therefore should be done by an external or by a palmar flap if possible. In the case of the index finger the pressure falls upon the palmar and radial aspects also, and the form of flap most suited to these cases, therefore, is a large external or radial flap, while in the case of the little finger the ulnar aspect bears most of the pressure and a large flap is therefore preferable.

An important practical point to remember is the large size of the head of the metacarpal, and a common mistake made in performing any of these amputations is to commence the incision too high above the joint line, when, if the form of amputation be one by incisions that diverge from one another, insufficient soft parts are left to cover the head of the bone. The incision for a simple disarticulation should never be begun much above the level of the joint line, which in the case under discussion is one-third of an inch below the prominence of the knuckle. The flexor and extensor tendons are divided at the upper limit of the incision and are allowed to retract. There is no need to close the flexor sheath when the amputation is being done for a whitlow, as it collapses spontaneously instead of remaining widely open, as it does after amputations below the metacarpo-phalangeal articulation.

Amputation by the circular racket incision. By a circular racket is meant one consisting of two incisions, a vertical and a circular one, the plane of the latter being at right angles to that of the former (see Fig. 47).

Indications. This is perhaps the most generally useful method for disarticulation at those metacarpo-phalangeal joints in which the cicatrix is not likely to be exposed to direct pressure: *e.g.* those of the middle or ring fingers, in which the neighbouring fingers protect the cicatrix from undue pressure. It is easy to perform and gives a good covering to the head of the metacarpal, but it is apt to leave a projection on the palmar surface (see Fig. 48) which, although it may impair the æsthetic result, is of no consequence as far as the usefulness of the hand is concerned. The amputation is particularly suited for labouring men.

Operation. The surgeon faces the tips of the fingers and seizes the particular finger to be operated upon in his left hand, while the assistant draws the other fingers away from it with bandage retractors (see Fig. 44). A circular sweep is made around the finger on the level of the free margin of the inter-phalangeal web, dividing only the skin and deep fascia. A vertical incision is then made in the middle line of the dorsum from the level of the metacarpo-phalangeal articulation (*vide supra*) down to the circular incision (see Fig. 47). The flaps thus marked out are raised with knife and forceps, the extensor tendon is divided at the level of the articulation, the edges of the flap are hooked back by an assistant, and the surgeon, taking the finger in his hand, hyper-extends it and bends it from side to side as may be necessary, while he divides the soft parts from the phalanx, cuts across the flexor tendon at the level of the base of the proximal phalanx, divides the glenoid and lateral ligaments, and disarticulates. No tourniquet is needed, as the vessels can be picked up as they are divided.

The wound is sewn up without a drainage tube, and gives a scar running across the head of the metacarpal bone from the palmar to the dorsal surface. The somewhat ugly projection left on the palmar surface when sewing up this incision may be obviated by taking out a small V-shaped piece of the flap in front (see Fig. 48); this makes the operation somewhat similar to one by lateral flaps.

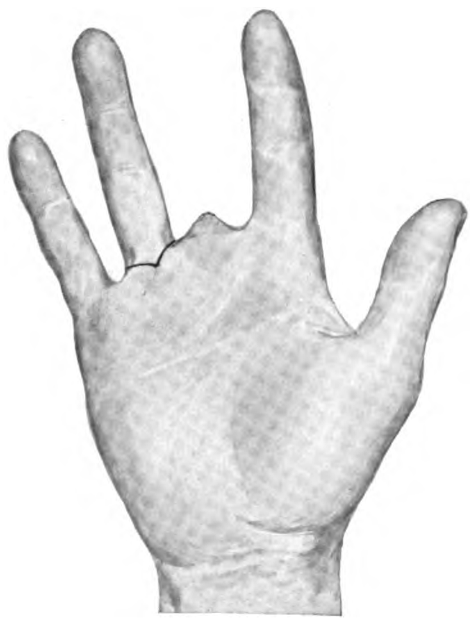

FIG. 48. THE PROJECTION LEFT AFTER DISARTICULATION AT THE METACARPO-PHALANGEAL JOINT BY THE CIRCULAR RACKET METHOD. The incision shown at the base of the ring finger is the modification of the ordinary transverse incision necessary to prevent the formation of the rather unsightly projection formed when the wound is sewn up, as is shown in the case of the middle finger.

Amputation by an oblique racket incision. By an oblique racket is meant one in which the plane of the head of the racket is inclined at an obtuse angle to that of the handle. In the case of the metacarpo-phalangeal joints, this particular form of amputation is only suitable for those cases in which the head of the metacarpal bone is to be removed as well as the finger; in other words, the operation is not a true disarticulation.

Indications. Removal of the head of the metacarpal bone along with the finger is practised for the sake of symmetry only, and possesses no other advantages. The strength of the grasp and the utility of the hand are impaired if the head of any of the metacapal bones be removed, and therefore in labourers and in all those who are desirous of preserving a strong grasp, the head of the bone should not be taken away. In women, however, the removal of the head of the metacarpal bone gives such a good æsthetic result that the fact of the finger having been amputated may actually escape notice; it gives a particularly good result in the index and little fingers.

Operation. The surgeon stands facing the limb, as before, and grasps the finger to be operated upon in his left hand, while his assistant keeps the other fingers out of the way, either with his fingers or with bandage retractors. The incision is commenced nearly half-way along the dorsal aspect of the metacarpal bone, and is carried vertically down it as far as the neck of the bone. Here it diverges to the right and is carried to the free margin of the web, then transversely across the palmar surface of the finger on a level with the highest crease at its base, and back again from the free margin of the web on the left side to the point at which it diverged from the vertical incision. This marks out a racket incision with an oval head (see Fig. 47). The flaps are dissected up as before, but in this case the dissection is carried further back and without opening the metacarpo-phalangeal joint. The transverse ligaments uniting the head of the metacarpal to the adjacent bones are divided, and the head and neck of the bone are cleared with a raspatory. The neck of the bone is then sawn obliquely from above downwards, from the dorsal to the palmar surface in the case of the third or fourth metacarpals; in the case of the index finger the line of section will be from above downwards from the radial to the ulnar side, while in that of the little finger the obliquity will be from the ulnar to the radial side.

FIG. 49. RACKET INCISIONS FOR DISARTICULATION AT THE METACARPO-PHALANGEAL JOINTS OF THE THUMB, INDEX AND LITTLE FINGERS. The drawing shows the way in which the handles of the racket are placed so as to be out of the way of pressure. It also shows the slight prolongation of the lateral flap on the side from which pressure is to be expected.

Fig. 49 shows the various modifications that may have to be made in these different forms of racket incisions. If either the thumb, index or little fingers are to be amputated by the circular racket method, the incision should always be planned so that the scar does not lie near the line of pressure. Thus, in the thumb or index finger the handle of the racket should be placed well on the ulnar side of the extensor tendon, and it is well also to make the circular incision around the phalanx not quite at right angles to the long axis of the finger, but somewhat oblique, so that the skin flap on the radial side is longer than on the opposite side. This allows the cicatrix to be drawn over to the ulnar side, out of the way of pressure. In the little finger the vertical incision should be on the radial side of the extensor tendon, and the flap should be longer on the ulnar side, so as to throw the cicatrix over towards the ring finger.

Amputation by a single large lateral flap (Farabeuf's amputation). **Indications.** This amputation is particularly suitable for the thumb, the index, or the little finger. In the case of the thumb or the index finger, the flap is cut from the radial and palmar surfaces, whilst in the case of the little finger it is fashioned from the ulnar and palmar surfaces. The incision for the flaps is identical in the two cases, and the operation is similar to that for the great toe (see p. 277). The stump in each case is very good, as the large flap covers the head of the bone easily, and the cicatrix lies well out of the way of pressure.

Operation. The surgeon stands facing the tips of the fingers and seizes the one to be operated upon in his left hand, dorsal surface uppermost, his assistant meanwhile keeping the adjacent fingers out of the way with a suitable bandage retractor (see Fig. 44). When operating upon *the right index finger* the incision is begun exactly on a level with the line of the joint just to the radial side of the extensor tendon, and is carried vertically down until it is just below the level of the free margin of the interdigital web; this will be nearly half-way down the proximal phalanx. It is then sloped outwards over the radial side of the finger with a slight convexity downwards until it reaches the junction of the inner with the palmar surface; thence it is carried upwards across the palmar surface to the junction with the interdigital web just below the highest transverse palmar crease. From this point it passes back across the dorsal aspect of the web by the shortest possible route to the point from which it started. This incision may be made in one sweep, the left hand raising and manipulating the finger meanwhile, but it is easier to do it in two.

In the case of *the left index finger* (see Fig. 47) the incision is marked out in the reverse direction, passing from the same starting-point as before to the interdigital web, then across the palmar surface of the finger, and finally back to the commencement of the incision. The edges of the skin are seized in forceps, and the flap is raised right up to its base. The extensor tendon is divided on a level with the joint, and the surgeon then takes the finger and disarticulates in the usual manner, the large flap being well retracted meanwhile. The easiest plan is to open the joint from the ulnar side and to complete the disarticulation by the division of the glenoid ligament and the flexor tendon.

Amputation of the thumb is done in almost exactly the same manner; that of the little finger is also similar, except that the flap is an internal instead of an external one (see Fig. 50).

Amputation by an elliptical incision. Indications. This amputation is particularly useful in the thumb, and really fashions a long palmar flap which is admirably calculated to bear pressure. In amputating the thumb the surgeon should always endeavour to save as much bone as possible, for, as Farabeuf remarks, the thumb is more valuable

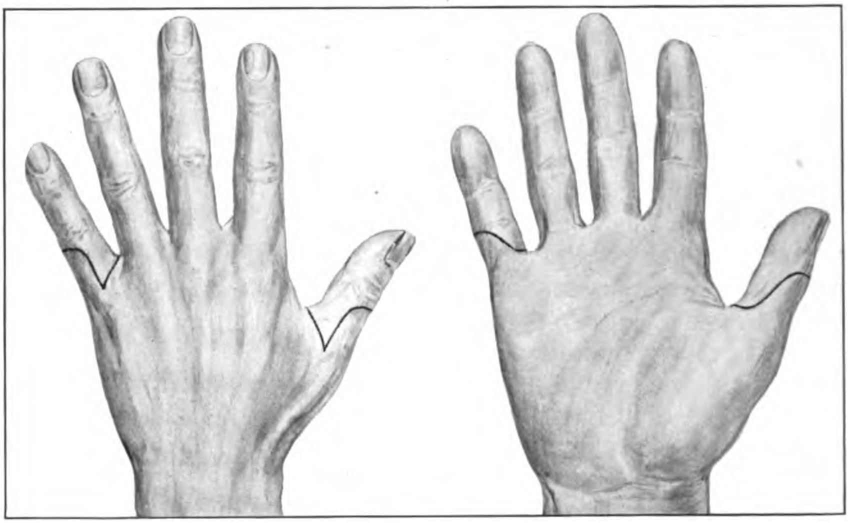

FIG. 50. FARABEUF'S AMPUTATION AT THE METACARPO-PHALANGEAL JOINTS OF THE THUMB AND LITTLE FINGER.

than all the other fingers put together, and even the smallest amount of bone saved is of the greatest importance, and therefore the surgeon should never disarticulate unless he is driven to do so, and should never choose that operation in preference to one that will retain a portion of the proximal phalanx merely for the sake of making a neat and tidy job. When amputating the thumb it must be remembered that the pressure falls largely upon the palmar and to some extent on the radial surface, and if possible, therefore, the cicatrix should be placed so that it does not fall in either of these situations.

Operation. The thumb is seized and abducted fully with the left hand, and a U-shaped incision with its convexity directed upwards is made on the dorsal aspect of the thumb with its highest point immediately below the line of the metacarpo-phalangeal joint. The lateral limbs of the incision run down the centre of the lateral aspect of the thumb (see Fig. 51). The best plan is to begin the incision almost on the level of the inter-phalangeal joint in the middle of the left-hand side of the thumb as it faces the surgeon with its dorsal aspect upwards, carry it up to just below the level of the metacarpo-phalangeal joint, then almost transversely across the dorsal aspect and down again on the

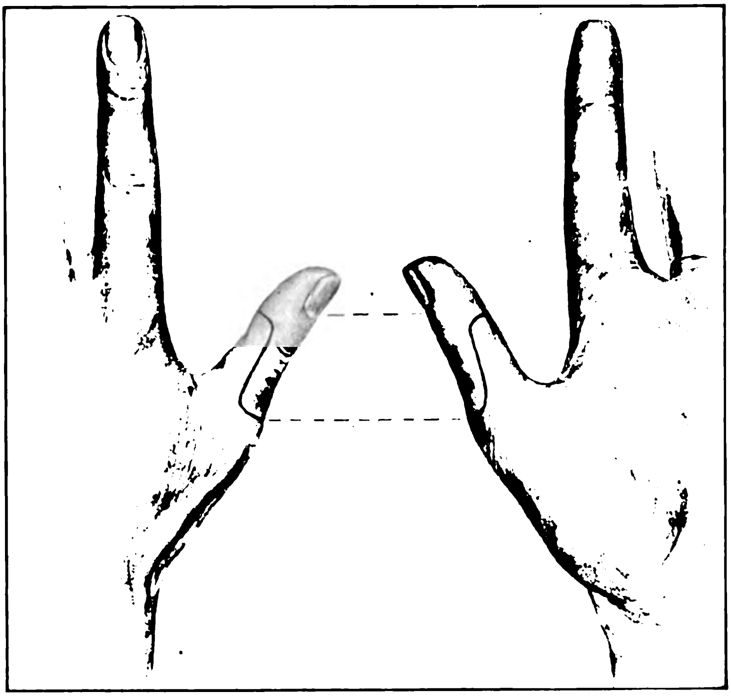

FIG. 51. DISARTICULATION AT THE METACARPO-PHALANGEAL JOINT OF THE THUMB BY AN ELLIPTICAL INCISION.

right-hand side to the level of the commencement of the incision on the opposite side. The thumb is then raised so that the palmar surface is exposed, and the two lower ends of the incision are joined by a curved incision convex downwards across the palmar aspect of the thumb from left to right just above the level of the transverse crease. The palmar flap is raised down to the tendon sheath, and the flexor tendon is divided opposite the base of the first phalanx. The surgeon then hyper-extends the thumb forcibly with his left hand and opens the joint by dividing the glenoid ligament with the point of his knife, the assistant meanwhile retracting the flap and fixing the metacarpal bone. A few touches of the point of the knife complete the disarticulation, the thumb being twisted from side to side as may be necessary.

Amputation of a digit with its metacarpal bone. **Indications.** Removal of a finger together with the whole of its corresponding metacarpal bone is rarely required except for severe crushes of the thumb; it is rare to find the entire metacarpal crushed in the case of the other fingers except when several are damaged. In septic cases it is generally possible to save a portion of the base of the bone, whilst in tuberculous cases it may be possible to excise the metacarpal bone alone without removing its corresponding finger; either of these procedures is preferable to removal of the finger and the entire metacarpal. In the case of the thumb it is important to remember that some portion of the metacarpal bone should always be left if this can be done safely, as the least part remaining gives a certain steadiness and mobility to the stump, which it would otherwise lack.

Amputation of the thumb with its metacarpal bone. At the present day this amputation is almost always performed by means of an oblique racket incision with a short handle and a long oval racket (see Fig. 52).

Operation. The surgeon stands facing the hand, which is held midway between pronation and supination, and seizes the thumb between his left thumb and index finger, holding it either horizontal or slightly flexed with the dorsal surface upwards. The point of the knife is inserted a finger's breadth below the radial styloid process over the tendons of the extensor ossis metacarpi (abductor pollicis longus) and primi internodii pollicis (extensor pollicis brevis) and carried along the metacarpal bone for an inch. The incision must not commence further out on the dorsal surface than the tendons mentioned, otherwise the radial artery will be damaged as it lies in the 'anatomical snuff-box'. The incision is now made to diverge to the surgeon's right hand so as to encircle the neck of the metacarpal bone, and it is carried round across the palmar surface to the free edge of the interdigital web quite close to its junction with the thumb. As the palmar portion of the incision is being traced out the thumb is hyper-extended. This is as far as the incision can be carried at one sweep, and the surgeon then flexes the thumb, and, passing his knife over the dorsal surface, continues the incision from the last point back around the neck of the bone, on the same level as on the opposite side, to the point at which the divergence from the middle line commenced, namely, an inch from the commencement of the incision.

In order to get satisfactory covering for the stump it is necessary to carry the racket sufficiently close to the neck of the bone, and for this purpose the line of what Farabeuf calls 'the opposition crease' should be followed. This is the crease seen on the palmar and radial aspects of the thumb just above the metacarpo-phalangeal articulation, which is brought into special prominence when that joint is flexed and the thumb adducted; it can always be made out.

The incision is deepened all round, and the extensor tendons are divided as they are met with in the wound; they will be divided at the

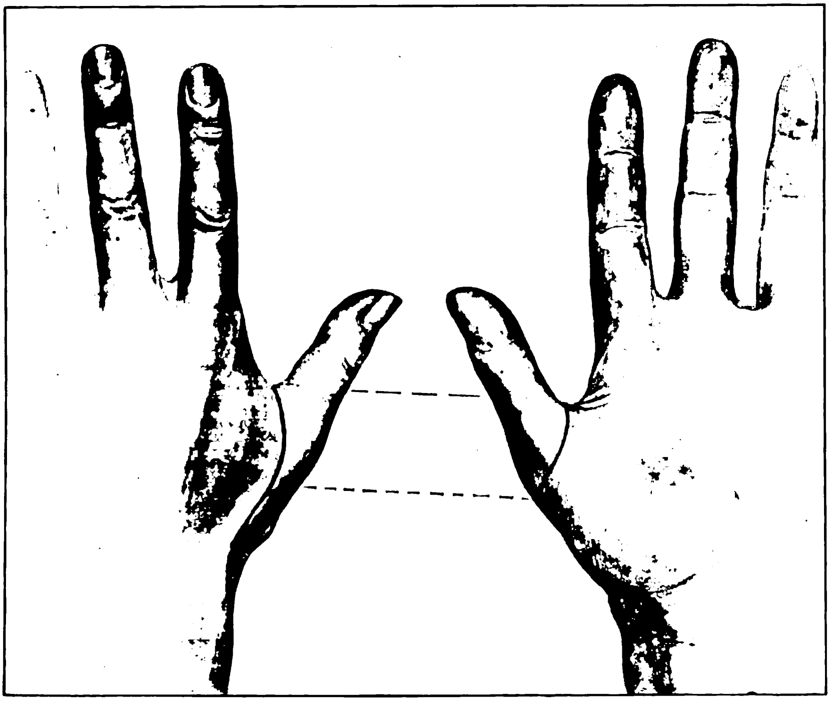

FIG. 52. AMPUTATION OF THE THUMB WITH ITS METACARPAL BONE BY THE OBLIQUE RACKET INCISION.

commencement of the incision in the left hand, but at the end of it in the right. The thumb is now grasped by the left hand and forcibly hyper-extended, and the knife is drawn across the palmar aspect of the neck of the bone, dividing the flexor tendon and all the soft parts. The muscles are dissected cleanly off the metacarpal bone right back to its base, the knife being kept very close to the bone throughout. The line of the carpo-metacarpal articulation may be identified by abducting and adducting or flexing and extending the thumb; as soon as it is evident, the point of the knife is inserted into the joint from the dorsal aspect and the ligaments on the outer side are divided. Care must be taken

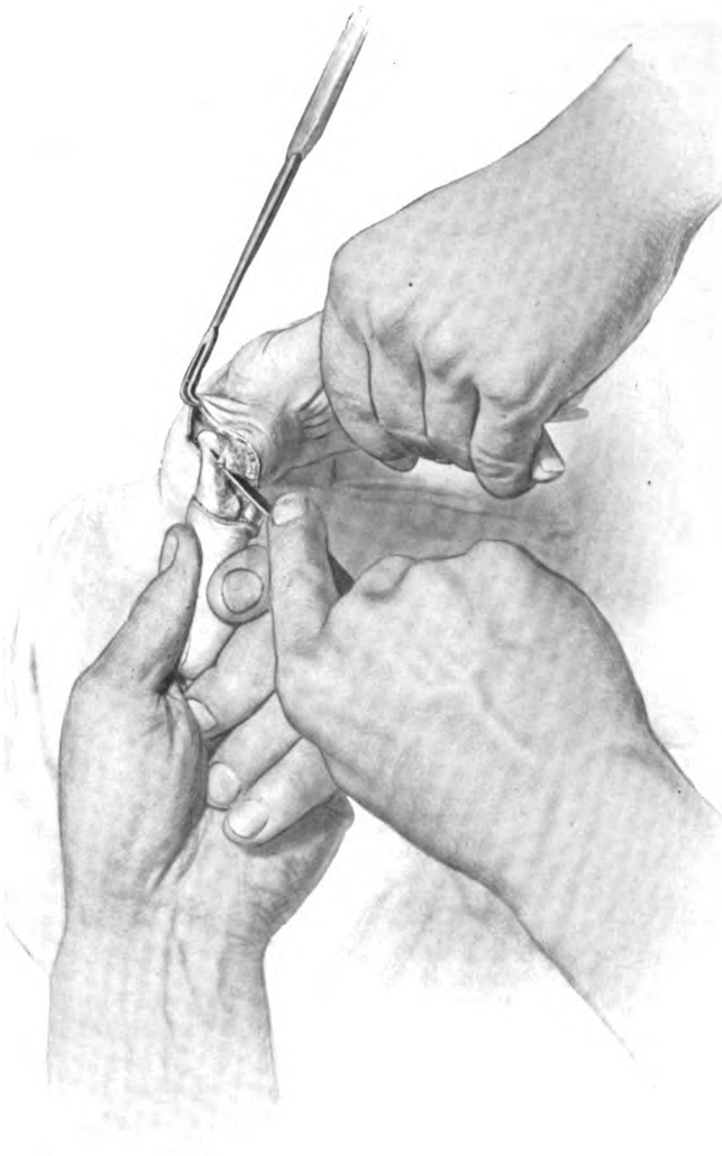

Fig. 53. Method of Manipulating the Thumb during its Removal. By grasping the thumb as shown in the figure the surgeon has perfect control over it and can twist it in any direction he pleases. The drawing shows the last few touches of the knife necessary to separate the ligaments on the inner side of the joint.

not to damage the radial artery, which passes between the first and second metacarpal bones at the upper end of the first interosseous space; the head of the bone should be twisted out as much as possible, and, as disarticulation proceeds, only the point of the knife is used to divide the ligamentous structures (see Fig. 53). The soft parts in the first interosseous space must be protected from injury during disarticulation by a suitable retractor.

Amputation of a finger with its corresponding metacarpal bone. The only finger for which this operation is really useful is the little finger. When disease affects the metacarpal bone as well as the finger, complete removal of the little finger with its metacarpal gives a neat appearance to the resulting hand, which is not materially weakened thereby. The peculiar manner in which the other metacarpal bones are wedged in between each other, however, renders their complete removal difficult, and therefore, if it be feasible, it is advisable to stop short of complete disarticulation and to divide the shaft of the bone before its base is reached. This renders the operation easier as well as safer, since it diminishes the chance of wounding the deep palmar arch, an accident of some importance owing to the difficulty of securing the wounded vessel; moreover, it avoids opening the general synovial cavity of the wrist, which would be a matter of importance were the mischief, for which the amputation is being performed, either septic or tuberculous.

When removing the little finger with its corresponding metacarpal bone, the only point of importance is to see that the cicatrix does not lie along the ulnar border of the hand, as in that case it will be exposed to injurious pressure; therefore the incision should be well on the dorsal surface.

Operation. The incision commences over the base of the fifth metacarpal well up on its dorsal aspect; it then runs down over its subcutaneous surface to just below its centre, whence it diverges to the ulnar side of the little finger just below the level of the free margin of the web; then it passes around the palmar aspect of the finger, nearly parallel to but just below the transverse crease at the base of the finger, to the junction of the little finger with the web, and from this point back to the point at which it diverged from the middle line (see Fig. 54). The incision, which is cut in an almost exactly similar manner to that for the thumb (see p. 226), is now deepened all round, and the soft parts are dissected up from the bone on the inner aspect of the wound. The flap is held aside by the operator's left thumb or forefinger, while the knife is passed around the neck of the bone, dividing the flexor tendon and the transverse ligament uniting the heads of the fifth and fourth metacarpals. This allows the former bone to be pulled inwards away from the latter, so that the interossei can be separated from the radial side of the bone right down to its base. Disarticulation is not easy; to facilitate it the surgeon may either make a transverse incision across the commencement of the handle of the racket, or he may prolong the incision inwards in a curved manner as recommended by Farabeuf (see Fig. 54). After the soft parts have been dissected up a little more, the interosseous ligaments uniting the base of the fifth to that of the fourth

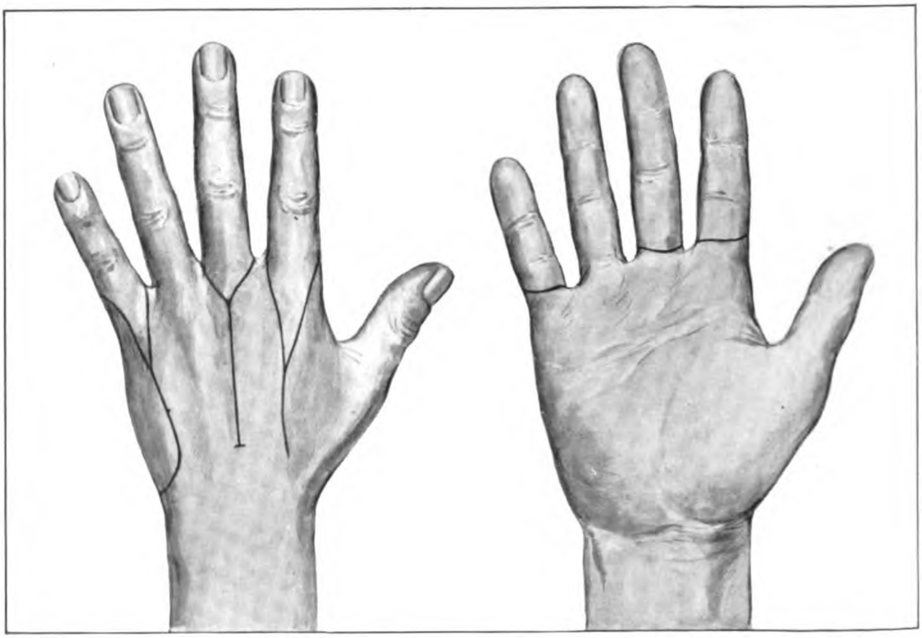

FIG. 54. INCISIONS FOR REMOVAL OF A FINGER WITH ITS CORRESPONDING METACARPAL BONE. The incisions shown are those appropriate for the particular fingers to which they are allotted. In the little finger the handle of the racket is curved away to the inner border of the hand, and the flap on the ulnar side reaches rather lower down than its fellow in order to get the cicatrix out of the way of pressure. In the case of the index finger the reverse is the case. In the middle finger the removal of the metacarpal bone is facilitated by the transverse incision at the upper end of the incision.

metacarpal are divided by a few touches of the knife, the finger being twisted in any desired direction in order to facilitate this.

The resulting stump is very good. No drainage tube is necessary either in this case or for the similar amputation in the thumb, as the dressing will keep the parts in good position if it be firmly wound round the hand after the sutures have been applied, and this suffices to prevent blood from accumulating between the flaps. The hand should be placed on a straight palmar splint, which fixes the wrist-joint; the forearm is carried in a sling.

Amputation of more than one finger with their corresponding metacarpal bones. The operations of this kind that may be called for are so diverse that it is useless to attempt a full description of the various procedures that may be employed; in every case the flaps must be planned so that as little as possible of the bone is removed. The nature of the injury itself will generally preclude any set operation, as the soft parts will probably be damaged very irregularly and in various directions, and the surgeon will often be able to patch his flaps together

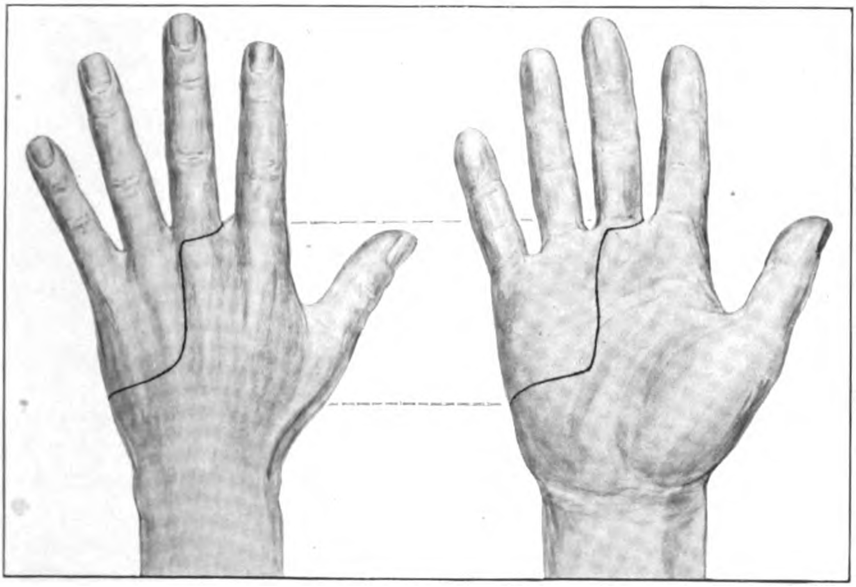

FIG. 55. INCISIONS SUITABLE FOR REMOVAL OF THREE FINGERS WITH THEIR CORRESPONDING METACARPAL BONES.

so as to save a larger amount of bone than he would be able to do with a set amputation. Fig. 55 shows a useful incision when two or three fingers are crushed and require removal. Occasionally it happens that all four fingers are crushed, as in machinery accidents, when Fig. 56 shows a good method of amputating. This is really a series of amputations by antero-postero flaps, the anterior being cut along the level of the palmar crease, whilst the dorsal flaps reach well below the level of the interdigital web to allow for retraction.

Fig. 57 shows an incision for the removal of the four fingers and their respective metacarpal bones by a somewhat elliptical incision. In a case like this the metacarpals would not be disarticulated, but would be sawn across near their bases.

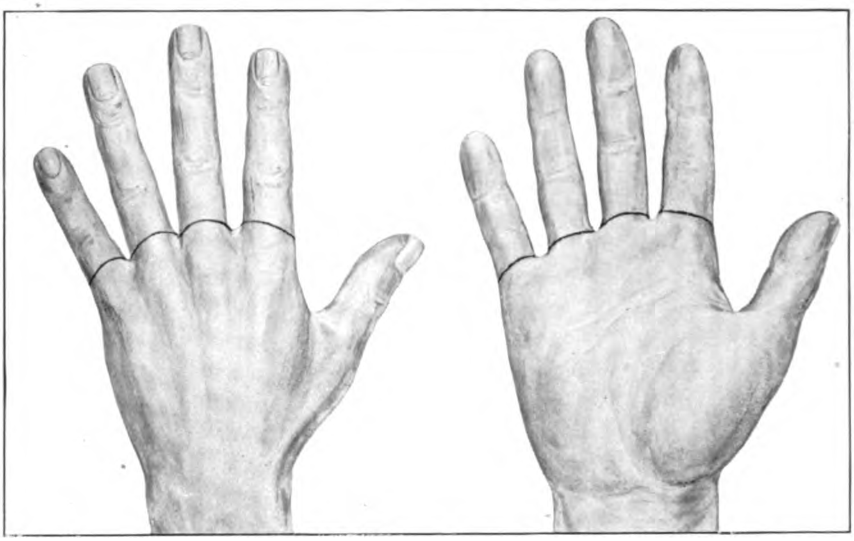

FIG. 56. INCISIONS FOR REMOVAL OF ALL THE FINGERS. These are really a series of separate incisions for each disarticulation.

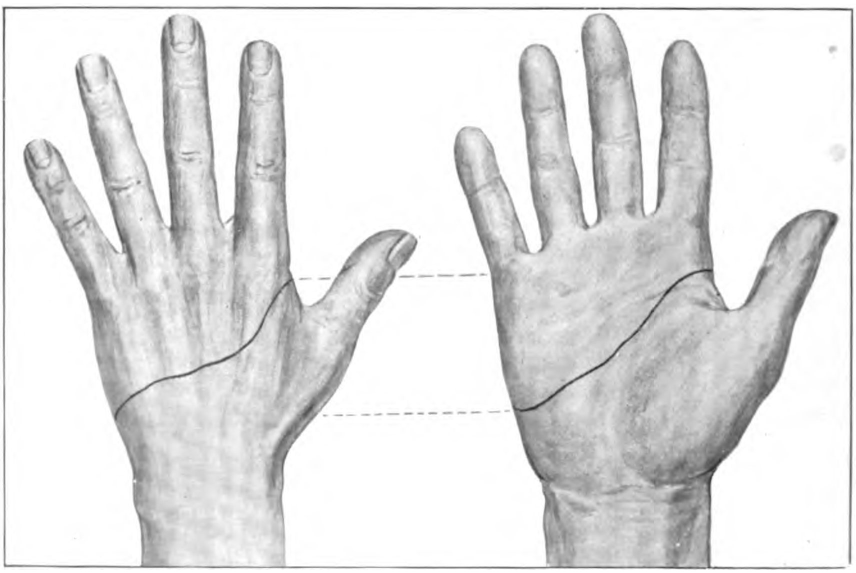

FIG. 57. INCISION FOR REMOVAL OF ALL THE FINGERS WITH THEIR CORRESPONDING METACARPAL BONES. This may be modified when it is desired to retain portions of the metacarpal bones.

DISARTICULATION AT THE WRIST-JOINT

This amputation should be practised in preference to one through the lower third of the forearm whenever the condition of the soft parts allows of it; the resulting stump is greatly superior, owing to the preservation of the inferior radio-ulnar joint, the insertion of the supinator longus (brachio-radialis) muscle, and the styloid processes, which provide good purchase for the artificial limb and preserve the movements of pronation and supination. It is not suited for tuberculous disease of the wrist, however, owing to the early implication of the tendon sheaths in the neighbourhood of the joint that occurs in that affection.

The artificial hand is generally fixed to the end of the stump by a firm band around the wrist, and therefore the cicatrix should not lie over the expanded ends of the bones, as in that case it will be compressed by the apparatus. A terminal cicatrix is not open to this objection, however, as it falls into the hollow space between the styloid processes of the radius and ulna and so escapes pressure. If a single flap be employed, it should be a long anterior one, as the integument of the palm is well adapted to bear pressure, and the cicatrix is drawn high up on to the dorsal surface of the forearm afterwards, where it is fairly well out of the way of undue friction. There are three methods of disarticulating at the wrist-joint, all of which are good: they are:—

(i) The Circular Amputation, (ii) By an Elliptical Incision, (iii) By a Single Anterior Flap. Of these the circular amputation is the best on the whole. It is done as follows:—

Amputation by a circular incision. A tourniquet is applied to the brachial artery around the middle of the upper arm, the forearm is drawn well away from the side and held horizontal by an assistant, whilst the surgeon stands facing the trunk with the patient's hand grasped in his left hand. The hand is now rotated over towards the surgeon's right, *i.e.* if it be the right hand it will be fully supinated, if the left, fully pronated. The knife is entered about an inch and a half vertically below the tip of the styloid process on the surgeon's left, and is carried across the upper aspect of the hand with a slight convexity downwards, and then round across the opposite side to meet the commencement of the incision, the hand being rotated meanwhile to meet the knife, so that its original position is exactly reversed when the incision is completed. This incision forms a circular sweep around the limb a full inch below the level of the wrist-joint (see Fig. 58) and should be deepened sufficiently to allow the skin to retract fully. The hand is then given to an assistant, and the surgeon raises the cuff of soft parts that the incision has marked out by pinching up the cut edge and dividing the cellular tissue with a few touches of the knife; the skin is raised until the tips of the styloid processes are exposed, and is kept well out of the way by an assistant.

The surgeon now takes the hand again, pronates it, flexes it firmly, feels for the styloid process on his left-hand side, and divides the lateral ligaments with the point of the knife, which is then drawn across the dorsal aspect of the joint, dividing the posterior ligament together with the extensor tendons, and finally the lateral ligament on the right-hand side (see Fig. 61). This opens the joint, which is then fully flexed, whilst the surgeon proceeds to separate from left to right the soft parts from the arch formed by the pisiform and unciform bones, twisting the hand and pulling it away from the forearm meanwhile, so as to define accurately the structures he is dividing. When this has been done, the

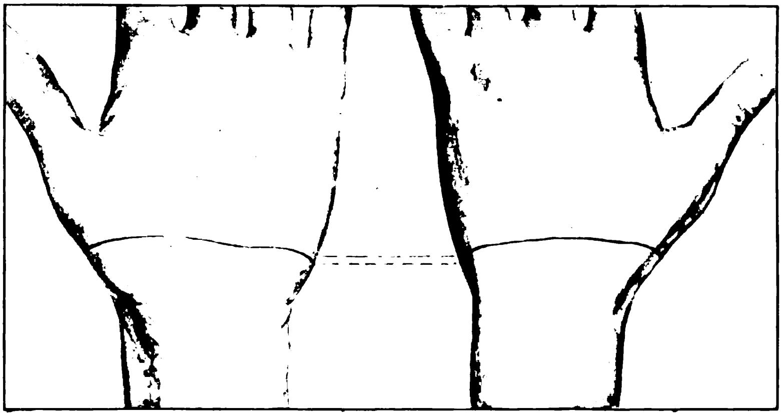

FIG. 58. DISARTICULATION AT THE WRIST BY A CIRCULAR INCISION.

sole connexion between the forearm and the hand is the flexor tendons, which are divided by a single clean downward cut.

The tourniquet is now removed, and the radial and ulnar arteries are ligatured; the median nerve is looked for and a portion removed. The wound is sutured so that the scar is transverse, and a small drainage tube is inserted at one end of it; this is removed in two days' time. The arm is put up on an internal angular splint midway between pronation and supination, and the forearm is carried in a sling.

Amputation by an elliptical incision. This operation is practically a modification of that by the long palmar flap (see p. 235), and will be only rarely used because, owing to the variable retractility of the skin about the wrist, it is rather difficult to cut the flap satisfactorily. As, however, the incision does not descend so far on the anterior surface as it does in the long palmar flap operation, the surgeon may be able occasionally to perform disarticulation by its means when the long palmar flap is inadmissible. The incision is an ellipse with its highest point on the dorsal aspect of the limb, half an inch below the level of the radio-carpal joint and slightly to the ulnar side of the middle line; its lowest point is on the palmar surface over the third metacarpal bone, three inches below the level of the radio-carpal joint (see Fig. 59).

The positions of the patient and the surgeon are the same as in the preceding operation; a tourniquet is applied to the brachial artery. The hand is fully supinated and held in the left hand, and the incision is commenced on the left side of the hand with a fairly long-bladed knife mark-

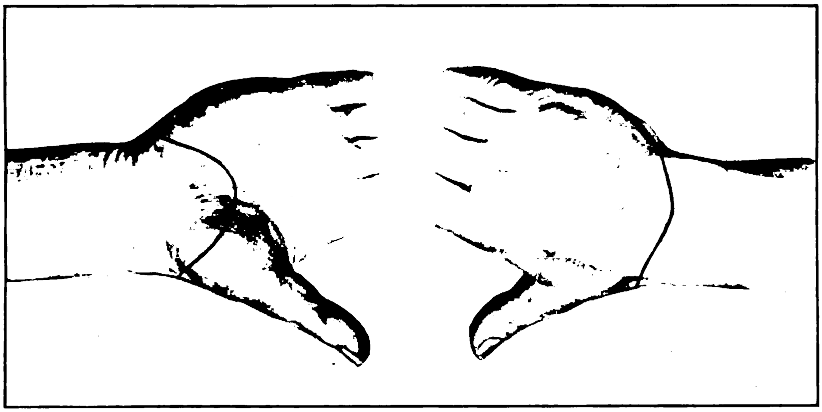

FIG. 59. DISARTICULATION AT THE WRIST BY AN ELLIPTICAL INCISION.

ing out the anterior or lower portion of the ellipse. This crosses the radial border of the hand on a level with the first carpo-metacarpal joint, and the ulnar border between the pisiform bone and the base of the fifth metacarpal; between these two points it takes a gently rounded sweep down to its lowest limit (*vide supra*). The incision goes down through the palmar fascia only in the centre of the palm, but down to the bones on each side. The hand is next pronated and the dorsal incision is marked out (see Fig. 59), the assistant pulling the skin well upwards before this is done. This part of the incision is carried down through the tendons until the posterior ligament of the wrist is divided and the joint is opened. Then the hand is fully flexed, and the lateral ligaments are divided from left to right as in the circular amputation (see p. 234), with which the remaining steps of the operation are similar.

Amputation by a long palmar flap. This is a U-shaped flap, the incision for which commences immediately below the tip of the radial styloid process, and ends half an inch below the tip of that of the ulna. The flap is rather more than three fingers' breadth in length, and is almost square, the edges being slightly rounded off. There is no dorsal flap, the horns of the palmar incision being joined by a cut across the dorsum without any convexity downwards, so that it is actually a little concave downwards after the skin has retracted (see Fig. 60).

The flap is somewhat difficult to shape nicely, owing to the projection of the thenar eminence, but it may help the surgeon in marking it out to remember that the outer or radial border of the flap, if prolonged downwards, would strike the interval between the index and middle fingers when the hand is fully extended and the fingers are close together, while the ulnar border of the flap if similarly prolonged would hit the

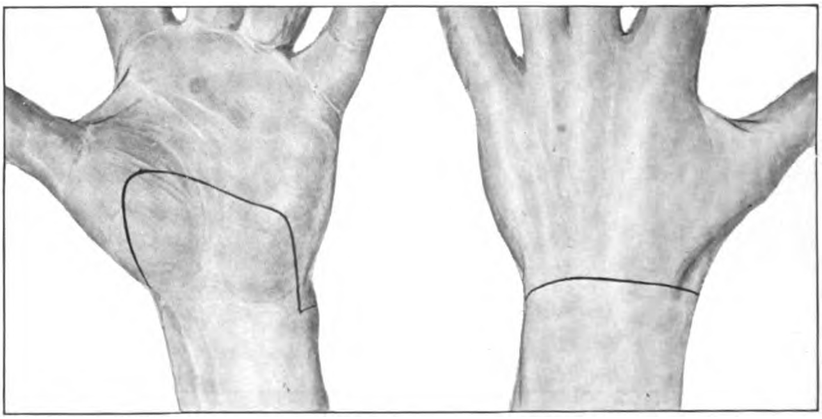

FIG. 60. DISARTICULATION AT THE WRIST BY A LONG PALMAR FLAP. Owing to the position of the hand from which the drawing was made the palmar flap appears to be somewhat oblique; it is, however, really almost rectangular.

interval between the ring and the little fingers. The two commonest mistakes made in this operation are to make the flap too long, and to fashion it so that its base is its narrowest part; it should taper very slightly from base to apex. The lower extremity of the flap does not reach quite as far down as the superficial palmar arch.

All the soft parts down to the flexor tendons are raised with the flap; they comprise the muscles in the thenar and hypo-thenar eminences, the median nerve, the palmaris longus tendon, and the termination of the ulnar artery and nerve. It is also well to raise the pisiform bone in the flap so as to avoid the risk of damage to the ulnar artery, which might occur were an attempt made to dissect the flap from it.

When the flap has been dissected up to the level of the styloid processes, it is folded back upon the flexor surface of the forearm and given in charge of an assistant, whilst the surgeon, pronating the hand fully, joins the terminations of the palmar incision across the dorsum by a transverse cut through skin and fascia only, which are allowed to retract fully. By a second sweep of the knife the extensor tendons are divided on the level of the edge of the retracted skin, and the knife is then applied to the left-hand side of the joint and made to divide first one lateral ligament, then the dorsal ligament of the wrist, and finally the lateral ligament on the opposite side, so that the joint is fully

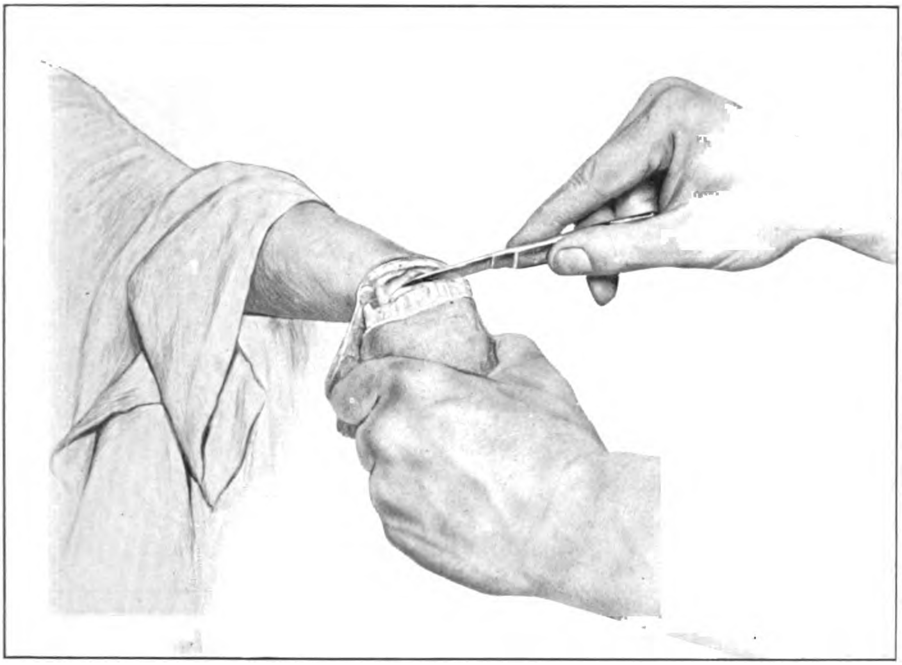

FIG. 61. THE METHOD OF DISARTICULATION AT THE WRIST. The drawing shows how the hand is grasped by the surgeon's left hand so that he is able to manipulate it during the disarticulation. It shows the knife being drawn across from the surgeon's left to right, dividing the ligamentous structures from the dorsal surface.

opened from the dorsal surface (see Fig. 61). With the wrist fully flexed, a few touches of the knife will divide the anterior ligaments, and nothing remains but to sever the hand from the forearm by dividing the mass of flexor tendons. This is done by straightening the wrist, pulling the hand well away from the forearm, passing the knife into the wrist-joint, and cutting firmly downwards with a few quick sweeps; during this procedure the palmar flap remains folded up against the flexor surface of the forearm, and must be carefully protected from damage by the assistant.

The ulnar and the superficialis volæ arteries require ligature, and the end of the median nerve should be dissected out of the flap and an inch of it removed. The pisiform bone is also dissected out without injuring the ulnar artery. The limb is put up as in the previous operations, the dressing being carried over the end of the stump from the flexor to the extensor aspect, so as to keep the hinge-like flap in place.

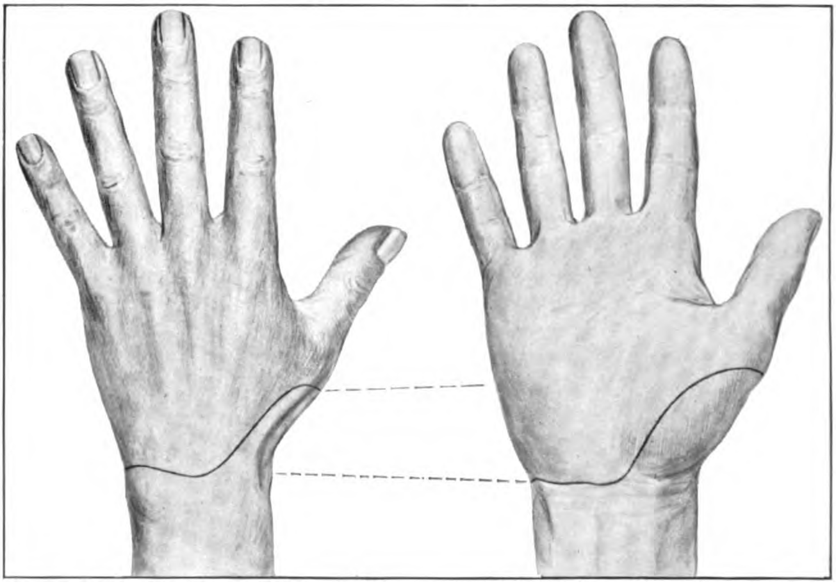

FIG. 62. DISARTICULATION AT THE WRIST-JOINT BY A LARGE EXTERNAL FLAP.

Two stout sutures taking a deep hold of the flap will be required to take tension off the more superficial stitches. A small drainage tube should be employed. The cartilage of the radio-ulnar arch is not interfered with unless it be the seat of disease, in which case it is removed with a gouge or chisel.

Amputation by a single external flap. This method may sometimes be adopted when the hand is crushed obliquely in machinery accidents, leaving only the tissues over the thumb intact. These structures make a useful covering for the stump. The incision is seen in Fig. 62, and commences at the junction of the outer with the middle third of the posterior aspect of the wrist immediately below the line of the joint. It is carried down, as shown in the figure, as far as the middle of the metacarpal bone of the thumb, when it crosses the radial border of that bone and is carried upwards on the thenar aspect to terminate at a point on the front of the wrist opposite to that at which it commenced. There is no flap on the inner side; the knife is drawn transversely round from the dorsal to the palmar termination of the first incision. In dissecting up the external flap all the muscles of the thenar eminence are included, and disarticulation is effected from the inner side. The method, although a satisfactory one, is inferior to the others previously described, and should only be used when the nature of the injury renders it necessary.

CHAPTER III

AMPUTATIONS OF THE FOREARM AND ELBOW

AMPUTATION THROUGH THE FOREARM

WHEN an amputation is done in the forearm it is very important to have the stump as long as possible, so as to provide sufficient leverage for the artificial limb. Even when only a small fraction of the bones of the forearm have been preserved, flexion and extension of the elbow can be practised, but the power over the artificial limb increases in direct proportion to the length of the stump, and therefore the bones should always be divided as low down as possible. Above the middle of the forearm it becomes of increasing importance, the nearer the elbow is approached, to save every fraction of an inch possible. When the stump is less than three inches, great difficulty is experienced in preventing it from slipping out of the socket, owing particularly to the action of the biceps tendon during flexion of the elbow, and with the short stump there is also naturally a decided loss in leverage. According to Little, it is impossible to get a forearm stump extending at least an inch and a half below the insertion of the tendon of the biceps, and amputation above the condyles of the humerus is to be preferred. The pressure to which the stump is exposed from an artificial limb falls upon its anterior and posterior aspects and not on its termination. After an amputation the bones of the forearm lose the mutual support derived from the inferior radio-ulnar joint; their lower ends approach one another somewhat, and finally occupy a position nearly midway between pronation and supination, the radius being thrust somewhat forwards and lying upon a plane anterior to that of the ulna. To ensure freedom of these movements every precaution should be taken at the time of operation to guard against union of the ends of the bones by osseous or fibrous adhesions. During flexion of the elbow the pressure exerted by any artificial limb falls upon the anterior surface of the limb over the end of the radius, whilst during extension it comes against the posterior surface of the ulna. From these considerations it follows that an amputation of the forearm by the circular method, or some modification of it, is peculiarly suitable, as it gives a terminal cicatrix and allows the bones to be divided on a lower level than any other form of amputation.

Owing to the tapering shape of the forearm, the ordinary circular amputation, as performed typically in the upper arm (see p. 259), is not suitable, at any rate below the middle of the forearm; in this situation

FIG. 63. THE CIRCULAR AMPUTATION. *Commencing the Incision.*

it has to be modified very considerably, since the muscular tissue has largely given place to tendons, and special means have to be adopted to divide these neatly and upon the same level.

In the upper third of the forearm the circular amputation is not so

FIG. 64. THE CIRCULAR AMPUTATION. *Finishing the Incision.*

suitable because so many of the muscles of the forearm arise from the upper third of the radius or ulna, and therefore it is difficult to get sufficient retraction of the muscular fibres after a circular amputation to allow the bone to be cleared and divided sufficiently high up, and in this situation, therefore, a flap amputation will be preferable.

The only methods that will be described here are the modified circular method and that by equal antero-posterior flaps. Many other methods are applicable in the forearm, but since it is of the highest importance to sacrifice as little of the bones as possible, only the two most economical methods are really the methods of choice, and such amputations as those by long anterior, posterior, or lateral flaps will only be

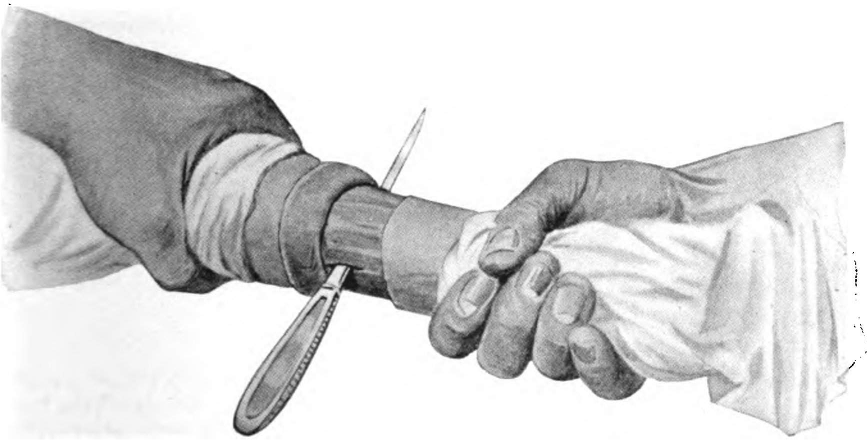

FIG. 65. THE CIRCULAR AMPUTATION BY THE CUFF METHOD. The knife is shown traversing the musculo-tendinous structures in the lower third of the forearm. The skin and subcutaneous tissues are turned back above as a regular cuff.

justifiable when the surgeon has to deal with a limb in which the soft parts are destroyed on one side whilst on the opposite side there are sufficient sound tissues to furnish a single large flap; here, of course, it will be more economical to amputate by a single large flap than to use equal flaps which must entail division of the bone on a higher level.

The circular amputation by the cuff method. This is the ordinary circular amputation slightly modified to meet local conditions, and is suited for amputation at or below the middle of the forearm.

Operation. The arm is abducted, the forearm is held horizontal by an assistant with its flexor surface upwards, a tourniquet is applied to the brachial artery, and the surgeon stands on the patient's right of the limb to be operated upon and determines the point at which he is going to divide the bones, at the same time estimating the antero-posterior diameter of the forearm at that level. With a knife having a blade about six inches long, a circular sweep is made around the forearm at a distance below the proposed point of bone section rather more than half this diameter; the extra length is given in order to allow for the retraction of the skin when cut. The knife is grasped as shown in Fig. 63, and the surgeon passes his hand and forearm beneath the limb, reaching round as far on to the flexor surface as possible, and pulling up the skin forcibly with his left hand meanwhile. The knife is drawn transversely round the limb with a light sawing motion until the circle is completed, when the knife will be held as shown in Fig. 64. Should there be any difficulty in completing the circular incision in one single sweep, it is

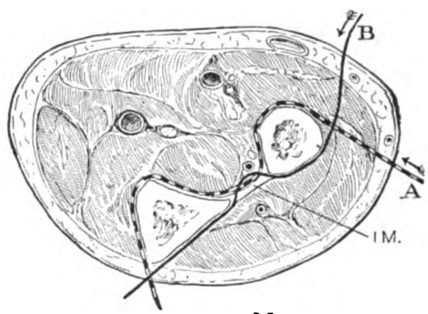

Fig. 66. A Diagram illustrating the Method of dividing the Periosteum and Interosseus Membrane. (*After Farabeuf.*) The diagram shows the course of the point of the knife as it is drawn across the bones for the purpose of dividing the remaining fibres of muscles, periosteum, and interosseous membrane (I.M.) previous to sawing the bones. Its path crosses the anterior aspect of the limb as denoted by the dotted line A; across the posterior aspect it is shown by the heavy black one B. The arrow indicates the direction in which the knife is drawn.

finished by drawing the knife in the reverse direction, from the end of the first incision to its beginning.

The incision should only go down through the deep fascia, and after it has been marked out it is gone over again carefully with the knife, so as to deepen it equally all round. The upper edge of the incision is now pinched up between the left thumb and forefinger, and the flap is raised from the muscles by a few touches of the knife held strictly at right angles to the surface and dividing the bands of cellular tissue connecting the skin with the deeper structures. The assistant pronates and supinates the forearm as the surgeon requires, and the skin is turned back in a regular cuff upon the forearm (see Fig. 65). This skin-cuff is raised until its lower margin is about an inch from the level of the proposed bone section, when the forearm is fully supinated, and the surgeon proceeds to divide the muscles and tendons.

A narrow-bladed knife, half as long again as the transverse diameter of the limb, is insinuated flatwise between the bones of the forearm and the soft structures in front of them until its point emerges from the opposite side. In introducing the knife its edge is downwards towards the extremity of the limb, and care is taken to keep its point as closely in contact with the anterior surface of the bones as possible, so as to

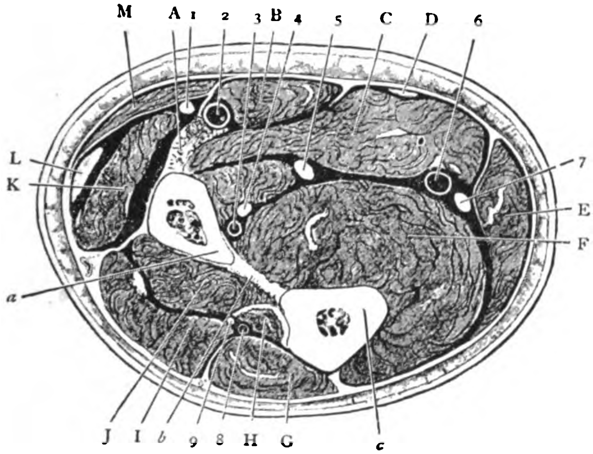

FIG. 67. SECTION ACROSS THE MIDDLE THIRD OF THE FOREARM (Cunningham's *Anatomy*). A, Pronator radii teres (insertion); B, Flexor carpi radialis; C, Flexor sublimis digitorum; D, Palmaris longus; E, Flexor carpi ulnaris; F, Flexor profundus digitorum; G, Extensor carpi ulnaris; H, Extensor longus pollicis; I, Extensor communis digitorum and Extensor minimi digiti; J, Extensor ossis metacarpi pollicis; K, Extensor carpi radialis brevior; L, Extensor carpi radialis longior; M, Brachio-radialis; *a*, Radius; *b*, Interosseous membrane; *c*, Ulna; 1, Radial nerve; 2, Radial artery; 3, Anterior interosseous artery; 4, Anterior interosseous nerve (underneath flexor longus pollicis); 5, Median nerve; 6, Ulnar artery; 7, Ulnar nerve; 8, Posterior interosseous artery; 9, Posterior interosseous nerve.

get it well beneath all the muscles and soft parts; it should pass close across the face of the interosseous membrane as it is carried across from one bone to the other. When the limb has thus been transfixed, the edge of the knife is turned upwards and, with a steady sawing cut, all the structures in front of it are cleanly divided on the same level. The knife is now introduced between the bones and the muscles on the posterior surface, the assistant maintaining the forearm in the same position meanwhile, and all the structures on the posterior surface are divided in a similar manner by turning the edge of the knife downwards towards the floor. The interosseous membrane, the periosteum, and possibly a few remaining muscular fibres are then divided (see Fig. 66), and the soft structures are pushed up with a rugine for about an inch. These should be retracted well above the point at which the bones are to be sawn, so as to allow this to be done easily. A three-tailed linen retractor (see p. 204) is employed to keep the soft tissues out of the way of the saw; the middle limb of the bandage is passed through the interosseous space and the lateral limbs are applied outside the bones. The saw is applied first to the ulna, which is the more fixed bone; when it has cut a groove in that bone it is made to saw the radius, the division of which is completed before that of the ulna.

The radial, ulnar, and interosseous arteries will require ligaturing (see Fig. 67); any tendons that are unduly long should be seized with forceps and cut short with scissors. It is always well to dissect out and remove a short portion of the median nerve; the ulnar nerve may be treated similarly if it is seen. The skin-cuff is now drawn down and its anterior and posterior surfaces are approximated so as to give a transverse scar. Two deep sutures of stout silkworm-gut will keep them in apposition, and their edges should be united by a continuous silk or silkworm-gut suture. A small drainage tube is inserted at the ulnar end of the incision, and moderate compression in the antero-posterior direction should be applied to the flaps by means of the dressings in order to keep them firmly in apposition. The limb is put upon an internal rectangular splint in a position midway between pronation and supination; the forearm is carried in a large sling.

Amputation by equal antero-posterior flaps. This method is most suitable above the middle of the forearm. The preliminaries are the same as before. The antero-posterior diameter of the limb at the proposed point of bone section is estimated, and the length of each flap should be about an inch longer than half this measurement, so as to allow for the retraction of the skin.

Operation. The incision is U-shaped, not semilunar, and the terminations of the incision will lie over the external border of the radius on the one side and in front of the ulna on the other. The incision commences a little below the proposed point of bone section, as a vertical cut to form one of the limbs of the U, at the lower end of which the knife is drawn transversely across the front of the limb, slightly rounding the corners, and finally up the opposite side of the limb to a point opposite that from which it started (see Fig. 68).

While the anterior incision is being traced out, the forearm is held horizontal and fully supinated, and the incision is deepened all round through the fascia so as to allow the skin to retract properly before the posterior flap is cut; to do this the elbow is flexed and the forearm held

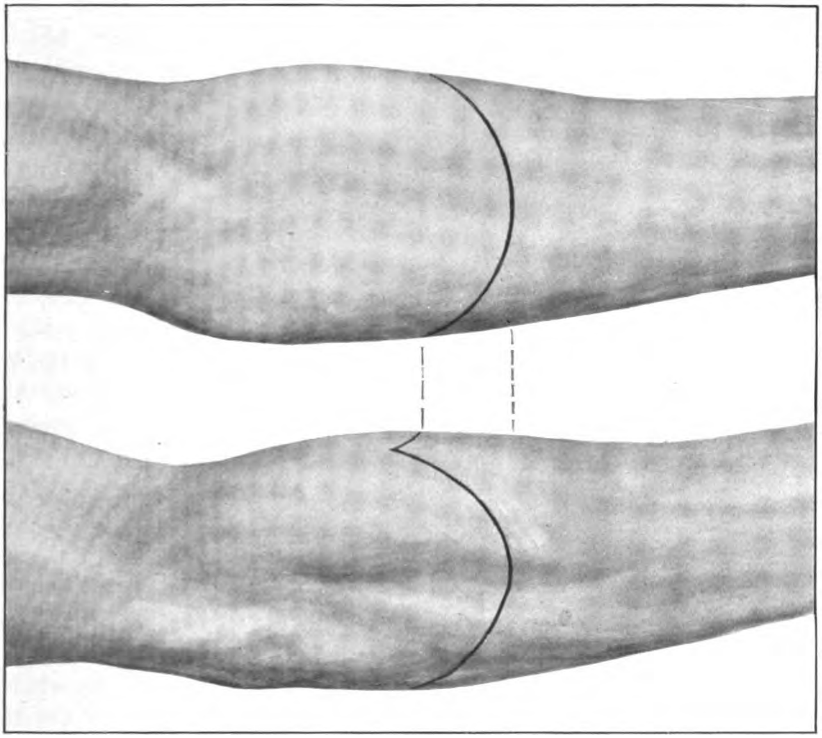

FIG. 68. AMPUTATION THROUGH THE FOREARM BY EQUAL ANTERO-POSTERIOR FLAPS. The level of bone section is nearly an inch above the angle of junction of the anterior with the posterior flap.

vertical by an assistant. The shape of the flap is similar to that of its fellow.

The operation may be finished by transfixing the muscles, or by dissecting up the skin flaps for about two inches, and then performing a circular division of the muscles down to the bone. The former method is preferable when the amputation is done in the upper third of the forearm, as the muscles are thereby enabled to retract sufficiently; when, however, the amputation is below this point, a circular division of muscles answers equally well, as the muscles then retract sufficiently to enable the bones to be sawn at the desired spot.

In order to transfix the muscles the knife is thrust between them and the anterior aspect of the bone at the upper extremity of the incision, while the limb is held horizontal and fully supinated by an assistant. The knife, with its edge downwards, is held nearly horizontal as it passes across the first bone; as it nears the interosseous membrane the handle is raised so that the point shall engage in this structure and divide it if possible. As the second bone is approached the handle is depressed, and the point coasts along the anterior surface of the bone between it and the muscles, when finally the handle is raised again and the point emerges from the opposite side. The muscles are now cut through somewhat obliquely downwards so as to form a muscular flap. The skin flap is pulled well up with the left hand as the knife cuts downwards and forwards, and an assistant puts the muscles on the stretch by extending the wrist; the result is that the muscles are cut a good deal shorter than the skin and retract well out of the way, at the same time leaving sufficient covering for the ends of the bones. A similar procedure is carried out on the posterior surface of the limb, but is more difficult owing to the depth of the interosseous space. There still remain muscular fibres and portions of the interosseous membrane that have escaped division, and the complete clearance of the bones at the proposed line of section may be done on each side by a single sweep of the knife, as shown in Fig. 66. The soft parts are retracted, a three-tailed bandage retractor is applied, and the bones are sawn as in the previous operation. The subsequent steps are the same as in the previous operation.

When a circular division of muscle is practised, the skin flaps are raised to within an inch of the proposed level of bone section, when the muscles are divided by a series of circular sweeps down to the bone. This is the best method of amputating in the middle of the forearm, as the muscles are divided above the origin of the tendons, the presence of which interferes with the clean division of the soft parts on one level; below this point the transfixion method already described for amputation in the lower third (see p. 244) should be adopted instead.

When the bones are divided above the insertion of the pronator (radii) teres in these operations, the action of the supinator (brevis) and the biceps is unbalanced, and therefore the upper end of the radius remains in a position of full supination. The after-treatment of the operation is similar to that for the previous case.

DISARTICULATION AT THE ELBOW-JOINT

This amputation is not practised as often as its merits deserve. Formerly it was rejected in favour of amputation through the upper arm, largely because of the fear of exfoliation of the cartilage, due to sepsis, which so often followed disarticulations, and which rendered the patient's convalescence long and dangerous. Nowadays, however, this risk need not be considered, and the superiority of the stump resulting from disarticulation over that following amputation through the upper arm is too great to admit of dispute. It is easy to cover the condyles of the humerus by suitable flaps, and the breadth thus given to the stump enables the artificial limb to be manipulated with much greater power and facility than it could be were it fitted to the round-ended stump resulting from amputation through the shaft of the bone.

Indications. Disarticulation should be performed, therefore, whenever it is feasible, in preference to amputation through the upper arm. It is a useful procedure for sarcoma of one of the bones of the forearm necessitating complete removal of the bone affected, and it may be possible to make use of it in cases of injury, when the radius and ulna are crushed so high up as to render it impossible to save any portion of them with safety to the patient. It is not, however, a suitable operation for tuberculous disease of the elbow-joint.

Disarticulation by the circular method. The operation has been done by a number of methods of which the circular or the elliptical are the most economical, as far as the soft parts are concerned; besides these methods, a single anterior or external flap, unequal flaps, or a modification of the racket incision have been used. The point of practical importance in doing the operation is that the condyles are somewhat difficult to cover, and it is well, therefore, to commence the incision some distance below the joint level, whatever flaps are to be employed; two fingers' breadth on the inner side and three on the outer will ensure plenty of covering. The skin over the region of the outer condyle retracts much more freely than that over the inner, and hence the difference in the measurements on the two sides.

The circular amputation is most useful for cases in which the tissues are damaged so high up that it is impossible to save any portion of the radius or ulna; it requires the least amount of sound soft parts of any operation in this region. It gives an excellent stump, the scar being transverse and drawn forwards upon the anterior surface of the humerus so that it is not exposed to pressure from the artificial limb. When only a single flap, usually cut either from the external or the anterior surface, is employed, its lower limit must reach almost as low as the middle of the forearm; such an amputation, therefore, would only be employed very rarely in cases of injury, and will be used chiefly for cases of disease such as sarcoma of bones of the forearm, in which the surgeon has not to consider the amount of the soft parts at his disposal.

Operation. The upper extremity is held horizontal and at right angles to the trunk by an assistant, a tourniquet is applied above the middle of the upper arm, and the surgeon stands on the patient's right of the limb to be operated upon. He first ascertains the level of the elbow-joint, the best guide to this being the head of the radius; the line of the joint is situated about a finger's breadth below the crease on the

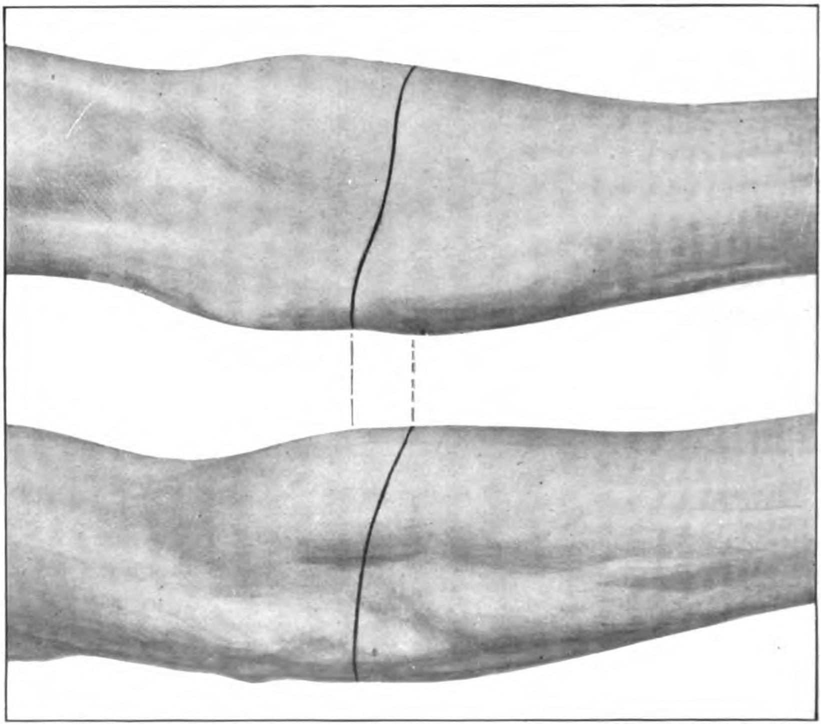

FIG. 69. DISARTICULATION AT THE ELBOW-JOINT BY A CIRCULAR INCISION. It will be noticed that the incision is not directly transverse, but inclined somewhat lower down on the outer side than on the inner; this is to counterbalance the greater retractility of the soft parts in that situation.

front of the elbow. A circular sweep is made around the limb, not exactly at right angles to the long axis of the forearm, but inclined so that it reaches a lower level on the flexor surface than on the extensor, and also lower on the radial than on the ulnar side (see Fig. 69). The incision will be about four fingers' breadth below the joint line in front and two behind, whilst on the outer side it will be three fingers' breadth below the condyle, and two on the inner side; this obliquity is to allow for differences in retraction of the skin. The incision goes through the deep fascia, which, with the skin, is raised to the level of the joint line by a few touches of the knife. The muscles arising from the inner condyle are divided as obliquely as possible, the soft parts are pushed up in front, the tendons of the biceps and the brachialis anticus are cut, and the anterior ligament of the elbow-joint is divided. The assistant now extends the elbow fully, and the surgeon opens the radio-humeral

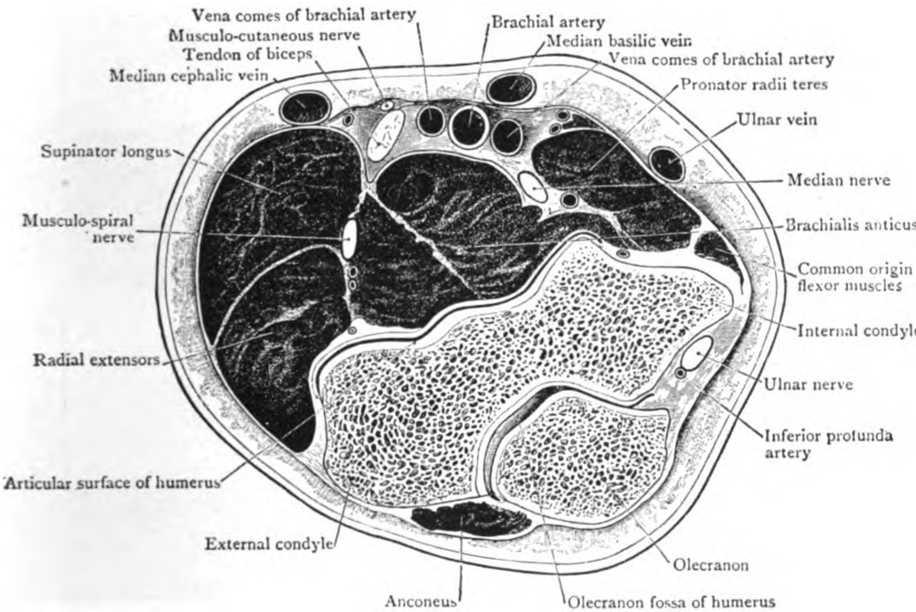

FIG. 70. TRANSVERSE SECTION THROUGH THE BEND OF THE ELBOW (Cunningham's *Anatomy*).

joint with a few touches of the point of his knife. The external lateral ligament and the muscles behind it are divided, and the knife is carried right up to the olecranon. By extending the elbow forcibly the coronoid process is made prominent, and the point of the knife can be swept around it and so through the internal lateral ligament and the ulnar nerve behind it. This leaves nothing to divide but the tendon of the triceps, which is brought into view by pulling the forearm forcibly downwards and hyper-extending the elbow-joint, when it can be divided at its insertion into the olecranon and the disarticulation is complete.

It now only remains to tie the brachial artery and the various articular branches and to identify and remove portions of the median, ulnar, and musculo-spiral nerves. Fig. 70 shows the position of these structures. The flaps are sewn up so that the scar is transverse, and the retraction of the skin on the anterior surface brings this over the front of the condyles. A drainage tube is inserted at the inner angle of the wound and removed in two or three days. The arm is surrounded with a piece of Gooch's splinting and bound to the side.

Disarticulation by an elliptical incision. This is really equivalent to an amputation by a single long anterior flap, and it can only be

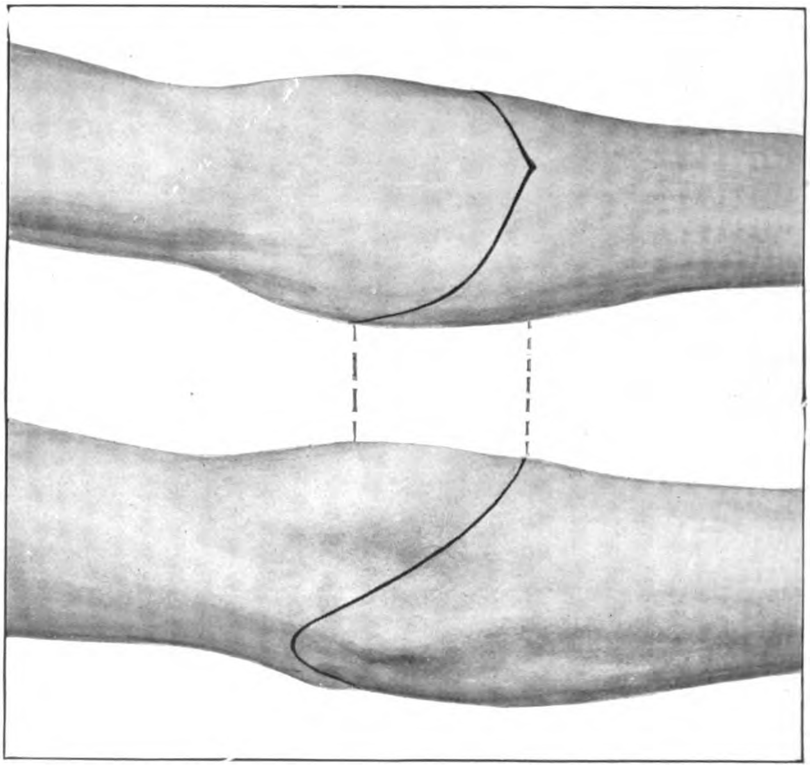

FIG. 71. DISARTICULATION AT THE ELBOW-JOINT BY AN ELLIPTICAL INCISION. The lowest point of the ellipse in front is slightly to the radial side of the middle line.

employed advantageously when the tissues on the front of the forearm are undamaged, whilst those on the back are lacerated almost up to the elbow-joint. This condition of the soft parts, however, is occasionally met with in machinery accidents, and it is advisable, therefore, to describe the method which gives a useful and sightly stump, and at the same time is fairly easy to perform.

The elliptical incision, marking out an anterior flap, has its highest limit behind, over the point of the olecranon, and its lowest in front, almost on a level with the centre of the forearm (see Fig. 71).

Operation. A tourniquet is applied to the upper arm, which is drawn away from the side, and the forearm is held by the surgeon, who stands facing the elbow. The wrist is seized with the left hand so that the fingers grasp the flexor surface and the thumb is on the posterior

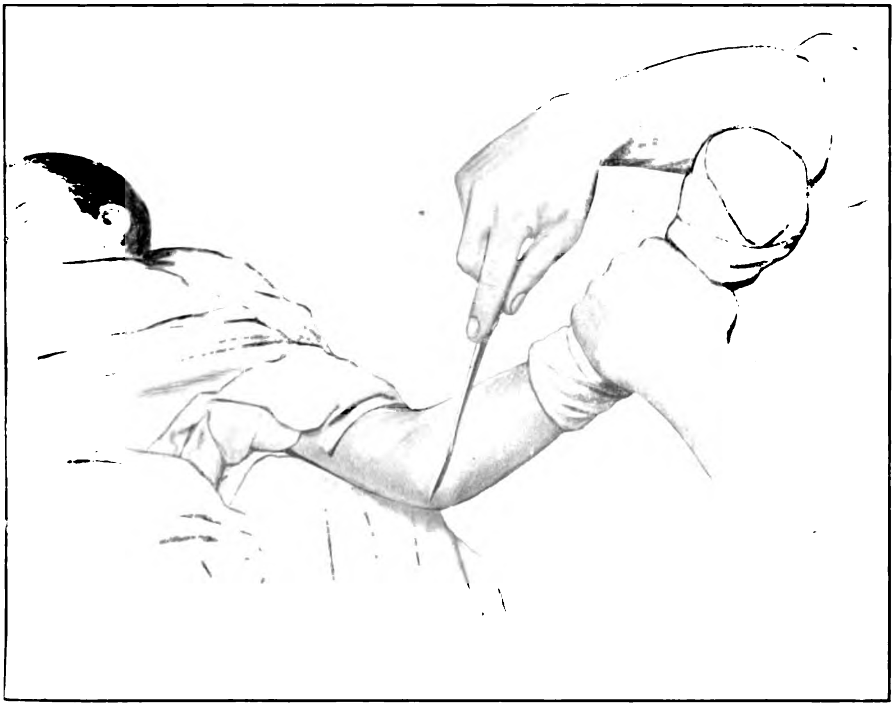

FIG. 72. COMMENCING THE ELLIPTICAL INCISION FOR DISARTICULATION AT THE ELBOW-JOINT. This shows the position of the patient's limb when commencing the incision. The limb is manipulated by the surgeon's left hand. If desired, the left little finger can be placed upon the lowest point of the ellipse on the front of the limb.

or extensor surface. At the same time the elbow is flexed at an acute angle, and the arm is rotated so that the hand is turned over towards the surgeon's right and the tip of the olecranon is rendered accessible (see Fig. 72). At this spot the point of the amputating knife, which should be about four inches long, is sunk through the skin, and an incision is made across the left-hand lateral aspect of the limb from behind forwards, the arm is supinated and extended so that the limb lies with its palmar surface uppermost when the knife is at the lowest point of the ellipse, which is rather to the radial side of the middle of the forearm. The knife changes its direction on reaching this point and is carried sharply upwards, whilst the elbow is again flexed and the forearm pronated and carried over to the surgeon's left, so as to expose the

FIG. 73. METHOD OF TERMINATING THE ELLIPTICAL INCISION FOR DISARTICULATION AT THE ELBOW-JOINT. This shows how the limb is rotated across from the surgeon's right to his left by means of his left hand.

right-hand lateral surface of the forearm, and allow the knife to be carried up to the point from which it started (see Fig. 73).

The incision is now deepened through the fascia all round so that the skin may retract, and the soft parts on the front of the limb are divided by transfixion in the manner already described (see p. 250). The skin should be retracted sufficiently to allow the knife to be passed across from one side of the joint to the other, and the muscles should be cut as short as possible. The wrist and fingers are hyper-extended while this is being done, in order to put the muscles fully on the stretch.

The anterior flap is now retracted and the front of the elbow-joint is exposed. It is easy to open the joint by a few touches with the point of the knife, to divide the lateral ligaments, and finally to complete the disarticulation just as in the circular amputation (see p. 250). All the subsequent steps are also similar to those of that amputation. The long anterior flap is brought round the end of the stump and the cicatrix falls over the posterior surface of the humeral condyles.

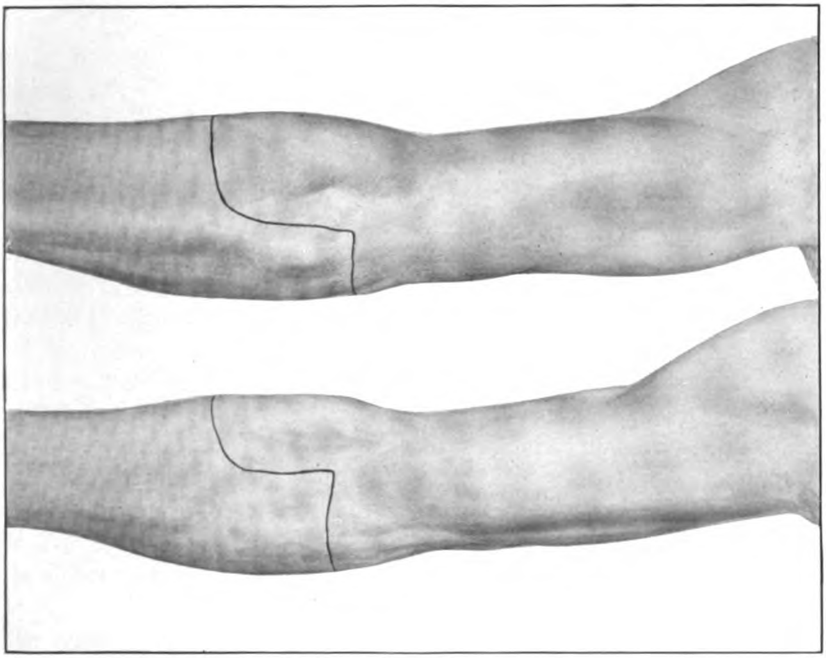

FIG. 74. DISARTICULATION AT THE ELBOW-JOINT BY A LARGE EXTERNAL FLAP.

Among the other amputations that may be employed the most important is perhaps that done by a *single external flap.* The steps of the operation are very similar to those already described for the circular and elliptical amputations, and Fig. 74 shows the incision employed. This amputation can only be called for very rarely, as it must be a rare accident that only leaves undamaged the particular area of soft parts required for the formation of this flap. The various other amputations that have been introduced offer no advantages over those already described and are not likely to be feasible when these are impossible; they will therefore not be described.

CHAPTER IV

AMPUTATIONS THROUGH THE UPPER ARM AND SHOULDER

AMPUTATIONS THROUGH THE UPPER ARM

WHEN amputating through the upper arm, the surgeon should remember the increased leverage and power imparted to the artificial limb by a long stump, and should therefore divide the bone as low down as the circumstances of the case will allow. The circular amputation, which enables the bone to be divided at the lowest possible point, is the amputation of choice, since the shape of the limb enables it to be done easily; indeed, the middle of the upper arm is the spot for which it is typically suited. There is no objection to the cicatrix being terminal, as no direct pressure is borne on the end of the stump; on the whole it is advisable to have the scar in this situation, as any pressure to which the stump is exposed falls upon its anterior and posterior margins, and not directly upon its end. Below the middle of the arm the soft parts retract nearly equally on the two surfaces of the limb, the retraction being slightly greater on the anterior surface owing to the pull of the biceps, but this is of little importance. Above the middle of the arm, however, the retraction of the soft parts is unequal on the two sides, and it is therefore easier to amputate by means of flaps or by some modification of the racket method.

A point of considerable practical importance is the ease with which large nerves may be caught in the scar and give rise to a painful stump; therefore, their ends must always be dissected out in the later stages of the operation and a portion removed.

In amputations through the arm below its centre the brachial artery may be compressed by a tourniquet placed around the upper part of the limb, but when the amputation is done above the mid-point there is no room for a tourniquet which will control the circulation and at the same time allow of sufficient retraction of the soft parts. It is possible to use an Esmarch bandage even as high up as the middle of the axilla if Wyeth's pins (see p. 195) or some similar means are used to prevent it from slipping. If the pins are used, they should be thrust through the deltoid above and the posterior fold of the axilla below. Unless they are used, however, the artery must either be controlled by compression above the clavicle, or it must be isolated and tied before it is divided.

The latter course will probably be preferred by the majority of surgeons, as compression of the artery above the clavicle is always uncertain and demands a most trustworthy assistant. In all amputations in the upper

FIG. 75. THE CIRCULAR AMPUTATION. *Commencing the Incision.*

arm the limb is held horizontal and at right angles to the trunk. The surgeon stands on the patient's right of the limb to be operated upon and pulls up the skin and manages the flaps with his left hand.

Three amputations will be described: (i) The circular amputation,

FIG. 76. THE CIRCULAR AMPUTATION. *Finishing the Incision.*

which is most suitable for the lower half of the arm; (ii) The amputation by antero-posterior flaps, which is best adapted for amputations just above the middle; and (iii) Amputation by a large external or deltoid flap, which is most suited for an amputation in which the bone is divided high up in the region of the surgical neck.

Circular amputation. The surgeon settles the point at which he is going to divide the bone, and then makes a circular incision through the skin at a distance below this point equal to nearly two-thirds of the antero-posterior diameter of the limb at the point of bone section. Before making his incision he grasps the limb with his left hand above the point at which he is going to divide the skin and pulls the latter forcibly upwards. The hand, holding the knife as shown in Fig. 75, is passed beneath the arm and commences the incision on the side of the limb opposite the operator and as far round it as possible. The knife is drawn round transversely to the long axis of the limb with a gentle sawing movement from heel to point, dividing the skin and deep fascia only (see Fig. 76); the entire circular incision may be completed in one sweep, but, if preferred, the direction of the knife is reversed after it has traced out about two-thirds of the incision, and is made to cut from the termination to the commencement of the first incision. The knife should pass very lightly over the inner aspect of the arm so as to avoid wounding the brachial artery, which lies immediately beneath the deep fascia.

When the circular incision has been deepened equally throughout down to the deep fascia, the skin is pulled up as firmly as possible by the left hand and the knife is drawn round the limb again on a level with the lower edge of the retracted skin, so as to divide the bands of cellular tissue uniting the skin to the deep fascia and to allow the former to be still further retracted by the grasp of the surgeon's left hand. This procedure is repeated two or three times until the skin has retracted for a good two fingers' breadth all round; the anatomical conformation of the parts allows this to be done without the necessity of turning up a cuff. Care is needed each time to avoid wounding the brachial artery.

The muscles, and with them the brachial artery (which is of course controlled by the tourniquet previously applied high up the arm), are now divided. This is usually effected by three circular sweeps of the knife round the limb as for division of the skin, each sweep going completely round and dividing about one-third of the thickness of the muscles. Each successive sweep is made on a level with the retracted edge of the muscles cut by the preceding one. Between each circular sweep the muscles are retracted either by an assistant or by the surgeon's left hand; the last incision goes down to the bone and divides the periosteum about an inch and a half below the point at which it is proposed to saw the bone. In this way a conical cavity is formed in the stump, at the apex of which lies the bone (see Fig. 77). The periosteum and the muscles are pushed up with a rugine for an inch and a half, when the point is reached at which the bone is to be divided. The soft parts are retracted by means of a double-tailed retractor (see p. 203), and the saw is applied in the usual manner, the limb being held quite horizontal meanwhile.

The brachial artery and any of its branches that are visible on the face of the stump are ligatured before the tourniquet is taken off, and the median, ulnar, and musculo-spiral nerves are identified, and an inch or so of each is removed. The stump is sutured by approximating the edges antero-posteriorly so as to make the scar transverse; a drainage tube is inserted at its outer angle and is removed in two or three days.

FIG. 77. APPEARANCE OF THE LIMB AFTER A CIRCULAR AMPUTATION. The figure shows the conicity of the stump, the skin projecting beyond the muscles and the cut edge of the bone forming the apex of the cone.

The limb is put up on a moulded splint of gutta-percha or Gooch's splinting, and fastened to the side.

Amputation by antero-posterior flaps. The flaps should be almost equal in length, the anterior being a trifle longer than the posterior, so as to allow for the greater retraction of the soft parts over the region of the biceps. The surgeon's position is the same as before, and, after determining the point at which he desires to divide the bone, he marks out a U-shaped flap half the length of the antero-posterior diameter of the limb at the point of bone section, beginning nearly an inch below that point (see Fig. 78); the anterior flap is cut first. It is of great importance that only the skin and fascia should be divided in this first incision, and the brachial artery preserved from injury, unless a tourniquet has been placed around the arm; when the amputation is above the middle of the limb, it is probable that no tourniquet will be used (see p. 256). The incision is deepened through the fascia so that the skin can retract equally all round, and a posterior flap almost as long

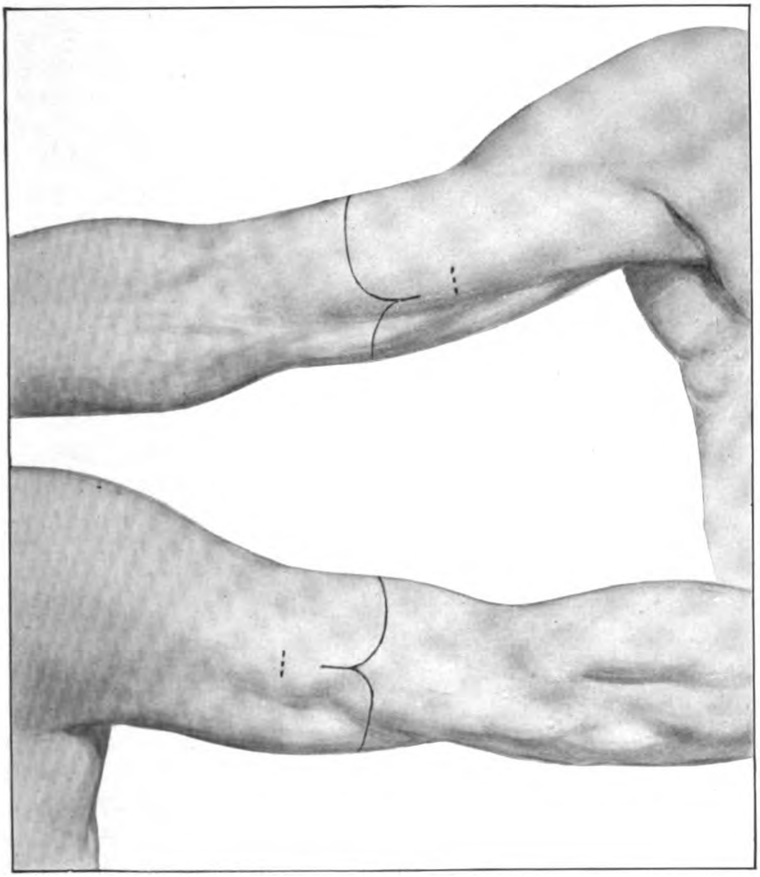

FIG. 78. AMPUTATION THROUGH THE ARM BY EQUAL ANTERO-POSTERIOR FLAPS. The dotted line marks the point of bone section, which is nearly an inch above the angle of junction of the flaps.

as the anterior is marked out by passing the arm beneath the limb and drawing the knife transversely across the back of the limb, with a slight rounding-off of the edges on each side; it is not necessary to raise the limb in doing this.

The next point is to secure the brachial artery, if the amputation is being done without a tourniquet. The deep fascia is incised freely over the inner edge of the biceps, and the artery, the pulsations of which are easily felt, is secured in Spencer Wells's forceps, after which it may be divided; the venæ comites are treated similarly. The muscles are now divided either by a circular sweep or perhaps better by transfixion, taking care to cut them as short as possible, so as not to leave too large a mass in the stump. The method of performing transfixion has already been described (see p. 247).

The periosteum and any remaining soft parts are divided by a circular sweep down to the bone, and are pushed back with a rugine until the level of the bone section is reached, when the saw is applied and the bone divided. The arteries are secured, and portions of the musculo-spiral (radial), median, and ulnar nerves are resected; a drainage tube is inserted in the outer angle of the wound, the limb being put up as in the preceding operation.

There are several other methods for amputating in the arm, and some of them may be useful occasionally according to the necessities of the particular case; for instance, amputations by equal lateral flaps, by a single long anterior flap, and others; but they do not require detailed description here.

Amputation by a large external flap. Amputation is not very often done in the upper third of the arm, as the surgeon usually has no alternative but to disarticulate at the shoulder-joint. Owing to the insertion of the muscles into the upper end of the humerus, a mobile stump is left even after the humerus has been sawn below the surgical neck, and this is of importance to the patient, as it renders his artificial limb much more useful. Since a terminal and even an adherent scar is not particularly objectionable in the upper extremity, owing to the pressure being exerted laterally, skin-grafting (usually inadvisable in a leg stump) may be employed to cover defects rather than performing a re-amputation. Moreover, in some cases, a good deal can be gained by removing wholly or in part the folds of the axilla, that is, the pectoralis major and teres minor. This has been done with good results and seems to be an operation worth doing in suitable cases. It is always advisable to retain any portion of the upper end of the humerus, even if only the head, rather than to remove it (as is necessary under similar conditions in the thigh), since the appliance is fitted much more easily when the glenoid cavity is filled.

Operation. The best result is given by a large external flap, which should be equal in length to rather more than the lateral diameter of the limb at the point of bone section, viz. the level of the surgical neck of the bone. The incision commences a good two fingers' breadth below the seat of bone section and is of the usual U-shape. The surgeon stands on the outer side of the limb and must take care that the flap is equal in width to half the circumference of the arm at the point of bone section. No tourniquet is applied, and the inner incision, which joins the upper ends of that marking out the large external flap almost transversely across the inner side of the arm, must be made carefully in order to avoid damage to the vessels which lie just beneath the fascia. After the skin has been allowed to retract, the deltoid is picked up between the left thumb and forefinger, and is cut obliquely from without inwards and from below upwards until the level of the bone section is reached. The next step is to expose, secure, and divide the axillary vessels, in order to reach which comfortably the attachments of the pectoralis major and the coraco-brachialis are picked up and either cut with a knife or stripped up from their insertion with a rugine. The nerves must also be divided, and this should be done as high up as possible. Finally the remaining structures, including the triceps, are divided by a clean sweep down to the bone, which is then sawn in the usual manner.

In order to increase the mobility of the stump, an attempt may be made to fasten the cut ends of the pectoralis major, coraco-brachialis, and latissimus dorsi to the portion of bone remaining.

Owing to the shortness of the stump it cannot be bound to the side, and movement will have to be restrained by the application of a moulded shoulder cap outside the dressings.

DISARTICULATION AT THE SHOULDER-JOINT

Indications. This type of operation is frequently called for both in civil and military practice. The limb may be torn off partially or entirely by machinery accidents, and in military practice the limb is often shattered right up to the shoulder-joint. In military practice, however, the operation is less common than formerly, owing to the facility with which conservative surgery can be practised. The same type of operation may be required for a malignant growth of the humerus; in these cases it will be possible to choose the most convenient and economical method of amputation, whereas in traumatic cases the condition of the soft parts at the disposal of the surgeon must largely influence his choice of method.

After this operation there is, strictly speaking, no stump left, and the attachment of the artificial limb is not always easy. The projection of the acromion, however, gives some sort of support, and it and the coracoid process should always be left intact if possible. The position of the scar is not of great consequence, but it is important that the large nerves should be cut as short as possible, as a painful scar from their implication in the cicatrix is not at all uncommon in this situation. Perhaps the amputations that give a vertical cicatrix are the best, as drainage is thereby facilitated.

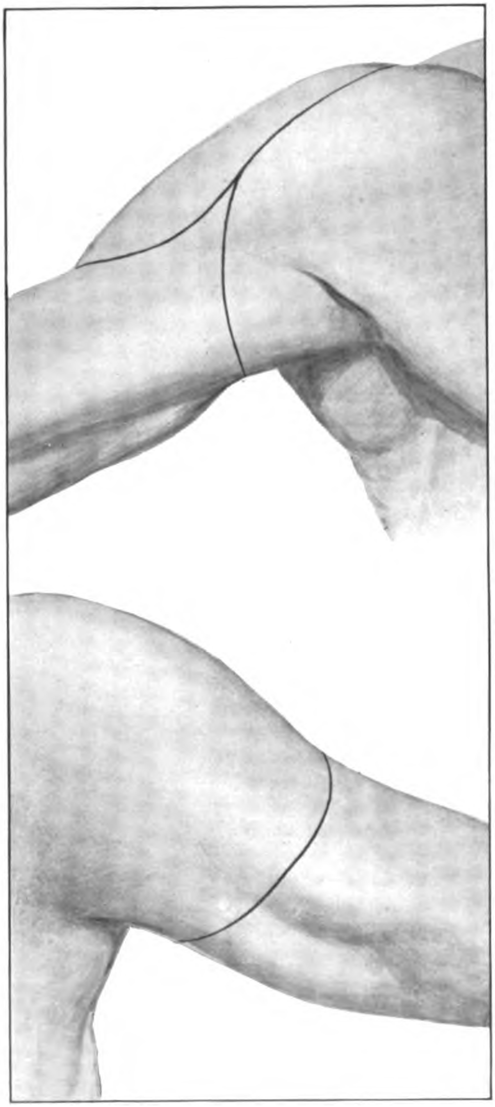

FIG. 79. INCISION FOR SPENCE'S DISARTICULATION AT THE SHOULDER-JOINT. The whole of this incision, except the inner limb seen in the upper figure, goes down to the bone.

The most important question in these amputations is the prevention of hæmorrhage, and, on the whole, it is best not to trust to compression of the vessels, but to expose the axillary artery and vein at an early stage in the operation, and secure and divide them before proceeding further with the operation. Compression of the subclavian by the fingers of an assistant is an uncertain method at best, and may be impracticable owing to the circumstances under which the surgeon has to work; a temporary ligature or a Crile's clamp (see Fig. 155) would be preferable.

A great number of methods of disarticulation have been practised, and Farabeuf in his *Manuel Opératoire* figures upwards of thirty. The vast majority of these, however, vary only in trifling and unimportant details and need not be considered; it will only be necessary to describe here two that are in common use, each of which is suited to a particular type of case. They are (i) Spence's amputation, and (ii) The modified racket operation. Spence's amputation (see Figs. 79–81) is best suited for cases in which the surgeon is at liberty to choose the method that pleases him best, and can obtain enough soft parts wherefrom to fashion his flaps; the modified racket method (see Fig. 82) is eminently suited for cases in which the surgeon desires to explore the parts and is uncertain whether he will eventually resect the joint or disarticulate. In special cases the surgeon will make use of whatever soft parts may be available for the fashioning of irregularly shaped

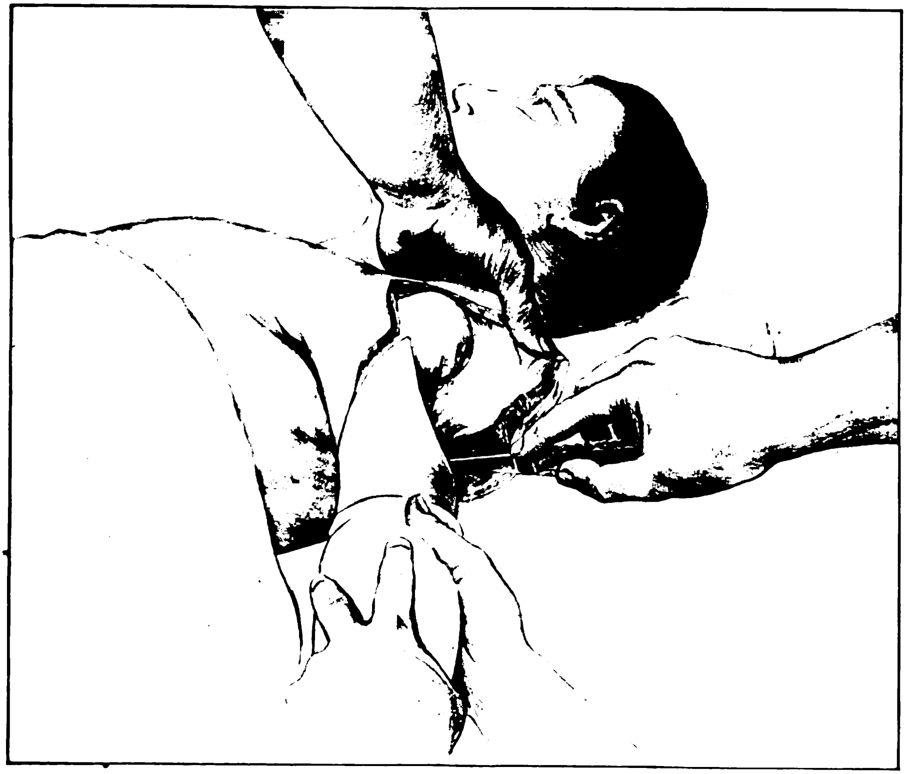

FIG. 80. RAISING THE OUTER FLAP IN SPENCE'S AMPUTATION. The deltoid is pulled away from the head of the bone with the left hand and is cut below obliquely from within outwards.

flaps to cover the stump. This is particularly the case in machinery accidents where any tags or flaps of skin that are uninjured may have to be pressed into the service to cover in the stump, or flaps may even have to be reflected from the thorax for the purpose.

Spence's amputation. Prof. Spence's own account of this operation will be found in his *Lectures on Surgery*, vol. ii, p. 662. It is done as follows:—

The arm is slightly abducted and rotated outwards. The surgeon stands on the outer side of the limb, in the case of the right arm facing the patient's feet, in the case of the left facing his head. The patient is brought to the extreme edge of the table. The incision is made with a broad, strong bistoury from a point just external to the coracoid process down through the clavicular fibres of the deltoid and pectoralis major, the humeral attachment of which is divided. The incision is now curved

FIG. 81. DISARTICULATION IN SPENCE'S AMPUTATION. The surgeon takes the head of the bone in his left hand, and, allowing the limb to hang vertically down, cuts downwards and inwards, following the inner limb of the incision, and so removes the arm. The ligatured ends of the large vessels can be seen on either side of the knife.

outwards and backwards as far as the posterior border of the axilla. Up to this point the knife is carried directly down to the bone. The incision is continued across the inner aspect of the arm through the skin and fat only to meet the original incision in a gentle curve (see Fig. 79).

The fingers of the left hand are now inserted into the incision and pushed down beneath the fibres of the deltoid, which are hooked up, pulled forcibly away from the capsule of the joint, and any remaining fibres divided obliquely from within outwards (see Fig. 80). With them comes the trunk of the posterior circumflex (humeral) artery, which is thus preserved uninjured.

The next step is to open the joint, which is done by cutting directly upon the tuberosities, and dividing the tendons inserted into them. With the point of the knife the remainder of the capsule and the broad tendon of the subscapularis are then divided, and the head of the bone falls away from the glenoid cavity. The surgeon then has the arm allowed to hang vertically, seizes the head of the bone in his left hand, and, introducing his knife across the joint, severs the remaining soft structures with a long sawing cut from within outwards (see Fig. 81). The large outer or deltoid flap is held out of the way by an assistant,

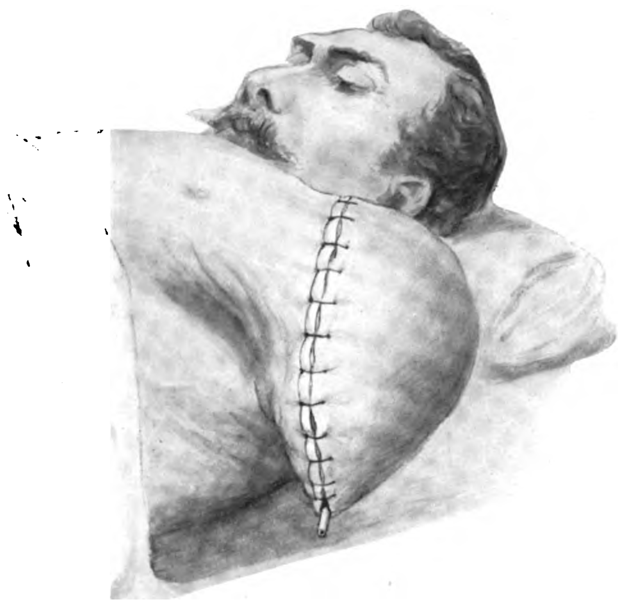

FIG. 82. STUMP OF SPENCE'S DISARTICULATION AT THE SHOULDER-JOINT.

and in making the division of the soft parts the surgeon follows carefully the lower edge of the flap on the inner side.

Spence had the bleeding controlled by an assistant, who slipped both thumbs into the wound behind the knife as it divided the structures on the inner side, and compressed the vessels in the inner flap between them and his fingers outside the flap. It is needless to say that this is a dangerous method; a far better plan is to deepen the incision carefully over the vessels as soon as the flaps have been marked out, and secure and divide artery and veins between double ligatures. When finishing the operation, the knife should be carried through the gap between these divided ends.

The modified racket method. The thorax is well raised and the affected side drawn over the edge of the table. The surgeon stands on the outer side, facing the head when the amputation is on the right side, and facing the feet when it is on the left. As in the case of Spence's amputation (see p. 266), the artery may be controlled by compression above the clavicle, by direct compression in the flap by an assistant's fingers as the vessel is divided, or, preferably, by deepening the incision over the vessel and securing it before the operation is completed.

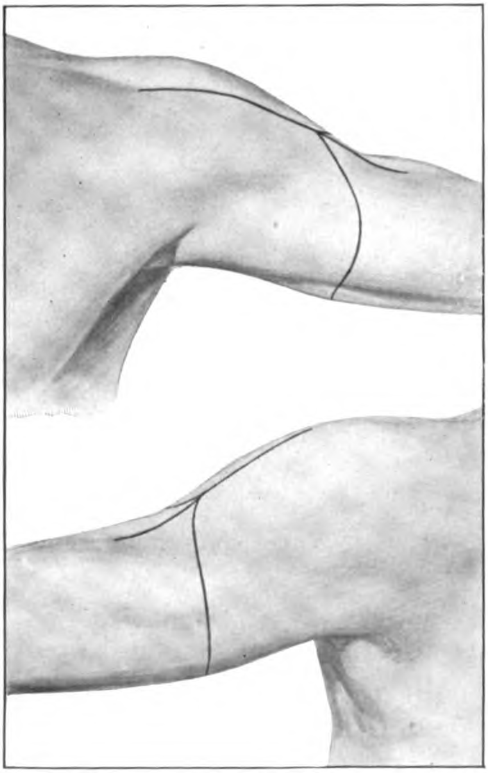

FIG. 83. DISARTICULATION AT THE SHOULDER BY THE MODIFIED RACKET METHOD. The prolongation of the vertical incision beyond the racket is only employed when a preliminary examination is desired.

The point of the knife is entered just below and in front of the point of the acromion, and a vertical incision about four or five inches in length is made down to the bone over the outer aspect of the arm. This exposes the head and neck of the humerus and opens the joint, and the surgeon is thereby able to gauge the extent of the mischief and to determine whether he will amputate or excise. Should he decide upon the former course, he enters his knife in the vertical incision at about its mid-point, and makes it pass obliquely downwards and inwards over the front and inner aspects of the arm until it is on the level of the insertion of the deltoid; it is then drawn transversely across the back of the limb and up over its outer side until it reaches a point in the vertical incision opposite to that at which it commences to diverge on the inner side (see Fig. 83). This incision should go through the skin and fascia everywhere, but care must be taken to avoid the axillary vessels as it crosses the inner side.

The muscles are divided in the following order:—The anterior fibres of the deltoid are seen in front, and these are raised and separated from the tendon of the pectoralis major; the latter is carefully divided at its insertion into the bicipital groove, the vessels beneath it being protected from injury meanwhile. The coraco-brachialis is then similarly isolated and divided. The inner or anterior flap is now retracted inwards, and the vessels are exposed lying upon the triceps, and surrounded by the cords of the brachial plexus which are isolated and divided as high up as possible; this exposes the axillary artery and vein, which are secured and divided just below the origin of the circumflex, and their ends retracted out of the way. The deltoid is divided down to the bone in the outer part of the wound on a level with the edge of the retracted skin, and the fingers are sunk in between its under surface and the head of the bone, and the posterior flap is pulled well away from the latter structure. The joint is now opened by dividing the muscles inserted into the great tuberosity in a direction transverse to the long axis to the limb, which is meanwhile brought down to the side of the trunk by the assistant. When they have been divided the joint is opened and the bone is rotated so that the remains of the capsule and the tendon of the subscapularis inserted into the lesser tuberosity, together with that of the biceps, may be divided in turn. The limb is now allowed to hang almost vertically, the elbow being inclined a little inwards beneath the table so as to thrust the head of the bone upwards and outwards from the cavity of the joint. The surgeon takes the head of the bone in his left hand and passes his knife between it and the glenoid cavity, so that it is easy to divide the remaining portions of the capsule; the head of the bone comes well away from the glenoid cavity, and the operation is completed by dividing the soft parts on the posterior aspect of the flap from within outwards, the knife cutting its way out on the level of the edge of the retracted skin. A good-sized drainage tube is inserted in the lower end of the wound and is kept in for three days. No splint is needed. The resulting scar is vertical.

CHAPTER V

INTERSCAPULO-THORACIC AMPUTATION

(REMOVAL OF THE UPPER EXTREMITY TOGETHER WITH THE SCAPULA AND A PORTION OF THE CLAVICLE)

THIS amputation, which is also known as the 'fore-quarter' amputation, removes not only the upper extremity, but also the shoulder and the contents of the axilla. It was introduced by Berger and often goes by his name.

Indications. (i) Extensive crushes in the region of the shoulder, such as machinery accidents, in which the upper extremity must be sacrificed and it is impossible to get a proper covering of soft parts without removing the scapula also. At the same time, every effort must be made to save the scapula if this can be done by means of plastic surgery. The patient is at a great disadvantage without it.

(ii) For sarcoma of the axilla or of the humerus which is too large or too widely infiltrating to be removed by any less severe procedure.

(iii) Occasionally it may be done for gangrene or spreading cellulitis affecting the shoulder-joint and the contents of the axilla.

It has been advocated for extensive recurrence following the usual operation for carcinoma of the breast, but it need not be discussed in this connexion, as disease that has recurred widely enough to render such an extensive operation necessary could hardly be dealt with satisfactorily by surgical measures.

The results of the amputation are excellent, and the risks appear to be little greater than those of disarticulation at the shoulder-joint. If the steps of the operation described below are carefully followed, the bleeding is only slight, and the shock is not greater than after amputation at the shoulder-joint.

Operation. Since a tourniquet cannot be applied, it is necessary to ligature the subclavian artery as a preliminary measure in order to control the bleeding, and this is perhaps the most difficult part of the operation. The affected shoulder is drawn well beyond the edge of the table and somewhat raised, while the arm is at the side and the head turned slightly to the opposite shoulder. An incision is made down to the bone along the upper surface of the clavicle from the sternal to the acromial end, the soft parts dissected off, and the bone divided. Care must be taken to avoid damage to the subclavian while clearing the clavicle, and the rugine must be kept very close to the bone while stripping off the subclavius muscle. A simple and efficient means of dividing the clavicle is by Gigli's wire saw, which can be passed round the bone without any risk of damage and divides it rapidly. A very convenient plan is to divide the bone first at the junction of the outer with the middle third; the inner portion of the clavicle is then

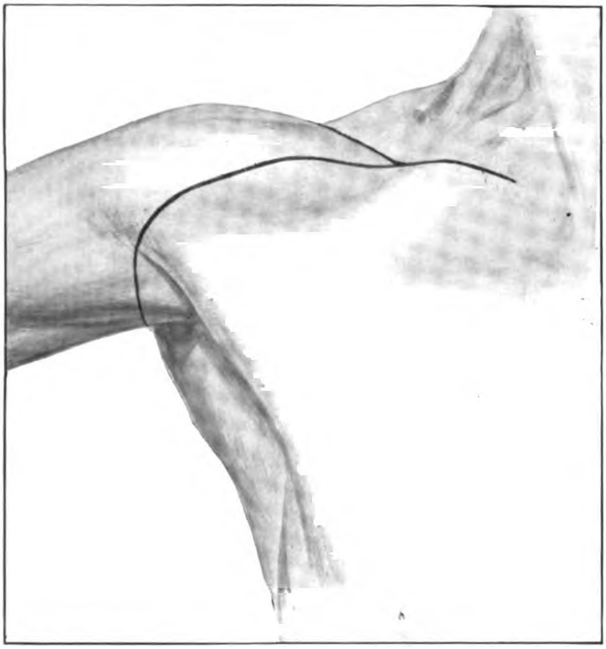

FIG. 84. THE ANTERIOR INCISION FOR THE INTERSCAPULO-THORACIC AMPUTATION.

seized in strong forceps and pulled upwards, the soft parts are carefully pressed away from beneath it, and two or three inches of it are removed.

After the subclavius muscle and its fascia have been divided, a little careful dissection will render evident the subclavian artery and its vein; each vessel is ligatured and then clamped about an inch below the ligature and divided between the two with scissors. It is a good plan also, as recommended by Kocher, to isolate and tie the ascending cervical, the superficial cervical, and the suprascapular (transverse scapular) arteries which arise from the subclavian artery and pass upwards or outwards in front of the scalenus muscle. The transverse cervical (transversalis colli) artery, which runs outwards and backwards to the vertical border of the scapula, may also be identified and secured, and if this be done the remaining steps of the operation will be almost bloodless. The brachial plexus is divided at the same time, and the divided lower ends are pushed down out of the way. It is an excellent plan to inject a few minims of a 4% solution of B-eucaine into the sheath of each cord some minutes previous to division, which should be effected with a very sharp

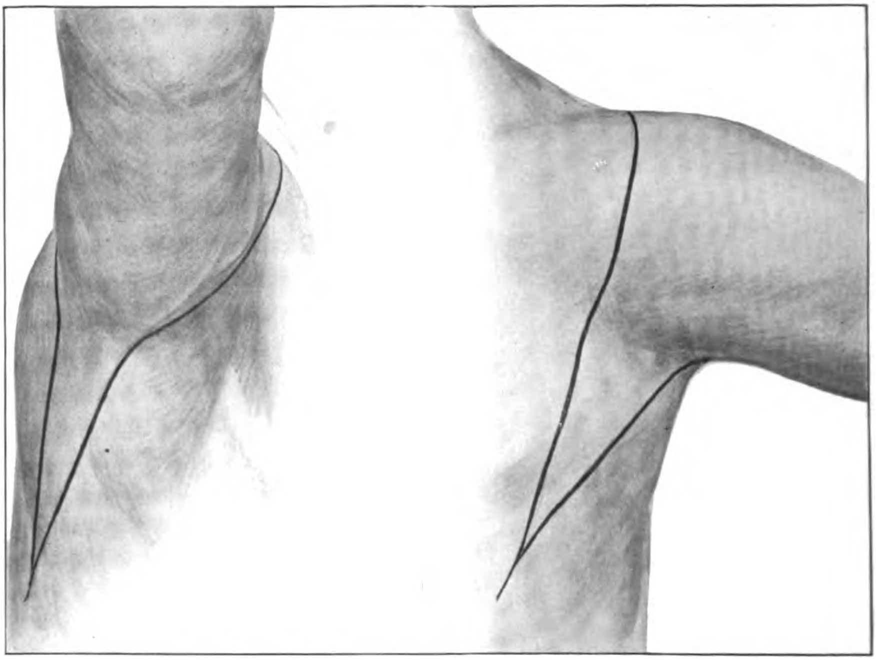

FIG. 85. THE POSTERIOR INCISION FOR THE INTERSCAPULO-THORACIC AMPUTATION. The left-hand figure shows how the anterior portion of the incision crosses the axilla.

knife and not with scissors, as there should be no crushing of the nerve elements. The artery should be tied before the vein, and, if it be desired to save as much blood as possible, the limb should be elevated for a few minutes after ligature of the artery and before the vein is secured.

The surgeon next proceeds to mark out his flaps. For this purpose he stands facing the patient and has the arm drawn well away from the side by his assistant. From about the centre of the incision along the clavicle the knife marks out a flap with its convexity towards the point of the shoulder, passing well on to the deltoid outside the tip of the coracoid process, and curving down across the junction of the anterior fold of the axilla with the arm, transversely across the inner aspect of the arm to its junction with the posterior fold of the axilla (see Fig. 84). At this point the assistant raises the limb almost vertically and pulls it forcibly upwards, so as to expose the back of the thorax, and the knife is carried downwards and inwards to the inferior angle of the scapula. The knife throughout should only go through the skin and deep fascia.

The pectoralis major is now divided in the line of the incision, and the fascia covering in the axilla is opened up, when the arm falls well away from the side and the axilla can be examined, and all its contents, consisting of glands, vessels, and nerves, can be stripped down out of the way. The incision is next deepened round to the back, and the latissimus dorsi is divided. This completes the formation of the anterior flap.

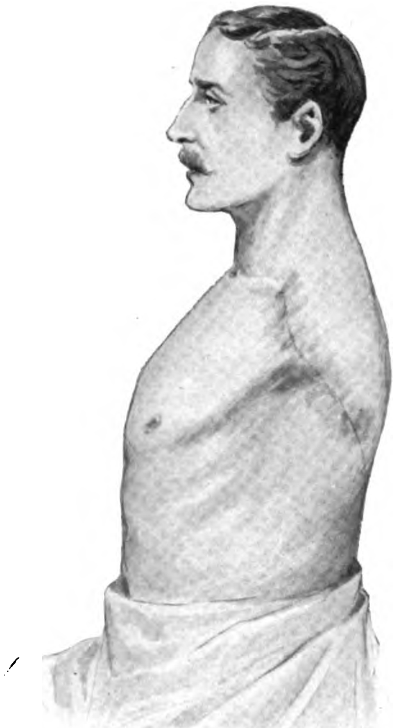

FIG. 86. THE CICATRIX LEFT AFTER AN INTERSCAPULO-THORACIC AMPUTATION. As a rule the flaps meet accurately and a neat cicatrix results.

The assistant now draws the limb forcibly across the trunk to the opposite side, so as to roll the patient over somewhat on to the sound side and expose the back. The surgeon stands to the outer side of the limb and prolongs the clavicular incision from the tip of the acromion over the shoulder and almost vertically down to meet the end of the first incision at the inferior angle of the scapula (see Fig. 85). This incision, like the first, only goes through the skin and deep fascia, after which the trapezius is divided throughout its whole length, and the surgeon, dissecting up the inner lip of the posterior flap, exposes the vertical border of the scapula and divides the muscles attached to it, which are the last structures to maintain the connexion of the upper extremity to the chest. The fingers are hooked beneath the omo-hyoid, the levator scapulæ, the rhomboids, and the serratus magnus (serratus anterior) in turn, and these muscles are divided as close to the border of the bone as possible. If the precaution mentioned above of securing the cervical branches of the subclavian be followed, little or no bleeding will accompany this step, otherwise there is generally free bleeding, which, however, is easily controlled by taking up each vessel as it is divided, and by practising the division of the muscles in successive stages.

After removal of the upper extremity entire in this way, the flaps come well together, and the scar runs obliquely downwards, outwards, and backwards (see Fig. 86). A drainage tube is placed in the lower angle of the wound, and the dressings are firmly bandaged on so as to obliterate all cavities in the region of the axilla. The patient should sit upright in bed, and should be carefully protected from cold, as pneumonia not infrequently follows the operation.

AMPUTATIONS IN THE LOWER EXTREMITY

CHAPTER VI

AMPUTATIONS OF THE FOOT

AMPUTATIONS OF THE TOES

THE amputations performed upon the toes are few in number. Except in the case of the great toe it is rarely necessary to do anything except a disarticulation at the metatarso-phalangeal joint, as the toes themselves are of little use, and removal of portions of them often only gives rise to a stump that gets in the way and is subjected to injurious pressure. The line of the metatarso-phalangeal joints lies about an inch behind (or above) the free margin of the web of the toes. The joint line of the great toe can be localized accurately by palpation, on flexing and extending the toe, and the prominence of the metatarso-phalangeal joints is formed by the head of the metatarsal bone. The ligaments of these joints consist of two lateral and an anterior or glenoid ligament.

AMPUTATIONS OF THE GREAT TOE

Disarticulation at the inter-phalangeal joint. The best amputation is by means of a single plantar flap, and the operation is similar in all respects to the corresponding operation on the terminal joints of the fingers (see p. 213). The toe is flexed and held between the left thumb and forefinger (see Fig. 87), and a transverse incision is made with a bistoury across the inter-phalangeal joint at right angles to the surface; the knife should enter the articulation at once. The lateral ligaments are divided by slight sawing movements, and the knife is carried on across the joint until it has divided the glenoid ligament, when its edge is turned downwards towards the tip of the toe, and it is made to cut downwards close behind the plantar surface of the phalanx until quite near the tip of the toe, when its edge is turned at right angles to the plantar surface and made to cut its way out. The flap thus cut should be quite square at the end, so as to fit accurately to the transverse incision on the dorsal aspect.

There will be few bleeding vessels to secure, as only the terminal branches of the digital vessels are divided and they are easily controlled by firm pressure. The flap is secured in position by two deep sutures of silkworm-gut, while the margins of the skin are approximated by a continuous suture.

The plantar flap may be raised by cutting it from without inwards; in this case the toe is hyper-extended, and the plantar flap is marked out first and then raised, taking up all the structures down to the bone. The flexor tendon and the glenoid ligament are cut together on the same level. When the plantar flap has been raised, the toe is flexed, and an incision is made transversely across the dorsal aspect exactly over the

FIG. 87. DISARTICULATION OF THE GREAT TOE AT THE INTER-PHALANGEAL JOINT. This shows the method of holding the great toe. The steps of the operation are similar to those of the corresponding operation in the fingers.

joint on a level with the base of the plantar flap. This divides the extensor tendon and opens the joint, and disarticulation can be completed by a few touches with the point of the knife. This method is a little slower than the preceding one, which on the whole is preferable, except perhaps in cases in which there is much limitation of movement in the joint.

Disarticulation at the metatarso-phalangeal joint. There are several operations for disarticulation at the great toe joint, and the surgeon will be largely guided by the particular affection for which the amputation is to be done, and the amount and distribution of the tissues at his disposal for the flaps. The most satisfactory method is probably that by a large internal flap, which is known by the name of Farabeuf, although it is by no means the easiest to perform successfully.

Anatomical points. There are certain points that must be borne in mind in all disarticulations in this situations. In the first place the large size of the head of the first metatarsal bone renders it impossible to get the flaps to meet accurately over it, unless the incisions are so planned that they do not diverge from one another above the level of the joint. Thus, if a racket incision be employed, the lower end of the handle of the racket must be carried down to or even below the joint level before the circular incision is carried round the toe, and if a Farabeuf's amputation be performed the incision must start at or even below the joint line. Another point of some importance is that the weight of the body is chiefly transmitted through the heel and the heads of the metatarsal bones, and that most of the weight falls upon the head of the first metatarsal. Special efforts should be made to preserve this structure in all cases, as its removal is apt to alter the mechanics of the foot entirely and to interfere seriously with locomotion. It is also very important to place the scar resulting from the operation where it will not be exposed to the risk of pressure from the boot, as otherwise intolerable pain may ensue, and another amputation may be necessary. The sesamoid bones should always be left in the flap, as their removal will endanger the vitality of the flap and may interfere with easy locomotion.

By a large internal flap (Farabeuf's method). In this amputation the head of the first metatarsal is covered by a large flap, derived partly from the internal and partly from the plantar aspect of the great toe, which is folded across over the head of the bone and united to the adjacent lateral aspect of the second toe just at the base of the web; the result is that the cicatrix lies deep in the web between the first and second toes, and is out of the way of pressure.

Perhaps the most important practical point to remember when performing this operation is, that if the incision be commenced *above* the joint line, the large size of the head of the metatarsal will prevent the flaps coming properly together over it, and some portion of the articular surface will therefore have to be cut away; this should always be avoided because of the important part the articular end of the bone plays in supporting the weight of the body.

Operation. The surgeon stands facing the sole, and has the foot projecting beyond the end of the table. The great toe is taken between the left thumb and forefinger and is flexed somewhat towards the sole. The knife is entered on a level with the joint line at the point where an imaginary inner joins an imaginary dorsal surface, supposing that the toe were mapped out into four surfaces, anterior, posterior, internal, and external; this point is slightly to the inner side of the tendon of the extensor hallucis longus. The incision is carried straight down the toe until the neck of the first phalanx is reached, and it is then curved inwards over the inner aspect of the toe until it reaches the junction of the imaginary internal and plantar surfaces. At this point the toe is firmly dorsi-flexed and the incision is carried obliquely upwards to the web between the first and second toes across the plantar surface of the toe. The toe is finally plantar-flexed somewhat, and pulled away from

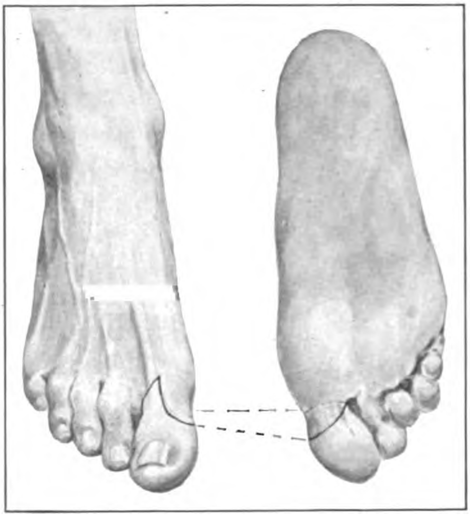

FIG. 88. FARABEUF'S DISARTICULATION AT THE METACARPO-PHALANGEAL ARTICULATION OF THE GREAT TOE.

the second toe, and the incision is carried from the web back by the shortest route to the point from which it started (see Fig. 88). The surgeon holds the toe in his left hand, the whole time, changing its position as the knife is carried round. The first two-thirds of the incision are made with one sweep of the knife, the remaining portion, namely, the incision from the web to the starting-point, is usually made by a separate cut in the reverse direction of the first. The incision should go down to the bone so as to avoid damage to the blood-supply of the flap, and the extensor tendon should be divided on the level of the joint.

The toe is now taken charge of by the assistant, while the surgeon dissects back the large internal flap thus marked out; while the flap is being raised the toe should be dorsi-flexed. When the level of the joint is reached the toe is fully dorsi-flexed, and the glenoid ligament is cut through just beyond the sesamoid bones, which are left behind in the flap. The lateral ligaments are divided by a few touches with the point of the knife, and then the phalanx can be twisted out and the extensor tendon divided, if this has not been done already (see Fig. 89).

There is little bleeding. Some of the digital branches may require ligature, but it is not necessary to use a tourniquet. The flexor sheath need not be closed, and no drainage tube need be used; it is unnecessary to pay any attention to the divided flexor and extensor tendons.

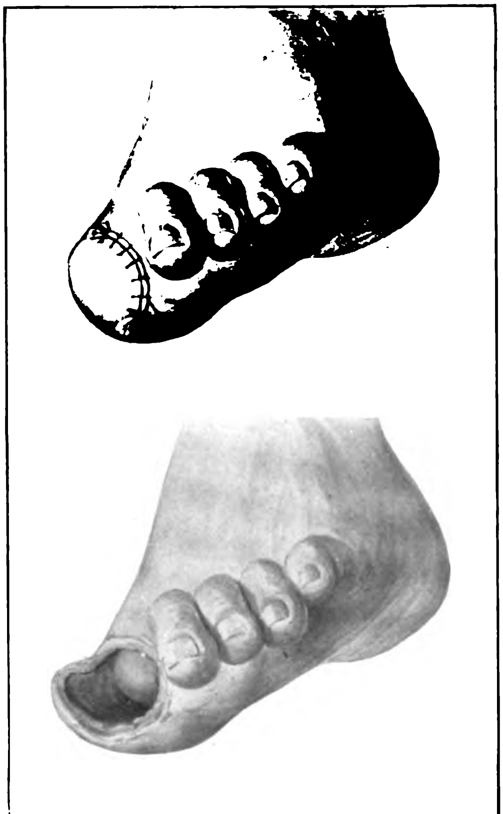

FIG. 89. THE STUMP LEFT AFTER FARABEUF'S AMPUTATION OF THE GREAT TOE. The figure shows how well the cicatrix is removed from all source of pressure.

By a large square internal flap. This method is suitable for the same cases as those to which the preceding method (to which it is very similar) is applicable, but it does not give such an artistic result. The incision is begun on a level with the joint line just internal to the extensor tendon, and is carried vertically down the toe as far as the base of the terminal phalanx. From this point a transverse incision is carried around the inner side of the great toe to a point on the plantar surface corresponding to that on the dorsum, and thence the incision is continued up the middle line of the plantar surface to the level of the web between the first and second toes. From the upper extremity of this incision a transverse cut is then carried round the outer side of the base of the great toe on a level with the free margin of the web, until it meets the dorsal incision, usually about one-third down its length (see Fig. 90). The flaps thus marked out are raised, and the bone is disarticulated as in the preceding operation.

The chief point of recommendation in favour of this operation is that it is easier for a beginner than Farabeuf's, which is apt to be performed clumsily until the surgeon has had some practice with it. Farabeuf's amputation, however, gives such an elegant and excellent stump that the extra study necessary for performing it with accuracy is well bestowed.

By the racket incision. The surgeon stands facing the sole as before, grasping the toe and plantar-flexing it between the left thumb and forefinger. The incision commences just above the line of the joint over the extensor tendon, and is carried vertically down to just beyond the level of the free margin of the web between the first and second toes,

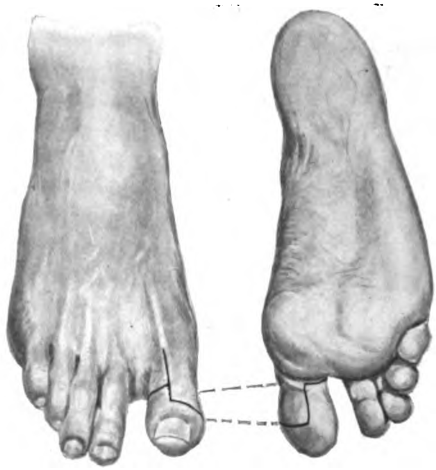

FIG. 90. DISARTICULATION OF THE GREAT TOE BY AN INTERNAL FLAP.

whence a transverse circular incision is made around the toe (see Fig. 91). The flaps thus marked out are raised from the bone, which is disarticulated as before. The sesamoid bones are left in the flap.

This operation, on the whole, is the simplest of all to perform, but nevertheless a good deal of attention must be paid to detail if the result is to be quite satisfactory. In the first place the flap is a clumsy one, and, when the soft parts are thick, it is somewhat difficult to dissect them back sufficiently to expose the line of the joint and disarticulate with ease. The result is that the beginner is apt to bury the point of his knife in the sole of the foot, and so to wound the arteries which are the main source of blood-supply to the flaps. The cicatrix, moreover, is not so completely removed from the risk of all pressure as it is in either of the preceding operations. But, on the other hand, there is never any difficulty in covering the head of the first metatarsal completely so long as the transverse portion of the racket incision is not commenced until the vertical limb or racket handle has been carried down beyond the level of the free margin of the web.

After-treatment. No splint is required for amputations of the great toe, and no drainage tube need be inserted. The best plan is to put in two stout deep silkworm-gut sutures to hold the flaps together, and to complete the approximation of the skin edges with a continuous silk or silkworm-gut suture. The patient may be allowed to get up after the fourth day, and to put his foot to the ground after a fortnight, when

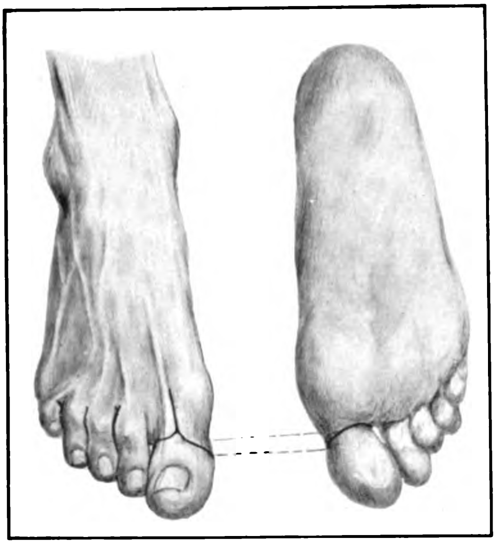

FIG. 91. DISARTICULATION OF THE GREAT TOE BY THE RACKET METHOD. This figure shows how the flaps on the two sides are unequal; that on the inner side extends somewhat further down in order to enable the large head of the metatasal bone to be covered.

the sutures should be removed. The stump will probably be quite sound in three weeks.

DISARTICULATION OF THE OUTER TOES AT THE METATARSO-PHALANGEAL JOINTS

It is not worth while to attempt to preserve portions of the three outer toes, as any portion so retained is not only useless but may be actually in the way and exposed to injurious pressure. It is well, however, to retain as much of the second toe as possible, as its presence tends to prevent deflexion of the great toe and the occurrence of hallux valgus. Except in the case of the little toe, the best method of removal is by the ordinary racket amputation already described for the great toe (see p. 280). The line of the metatarso-phalangeal articulation is one inch above the web, and the handle of the racket should commence just above this point directly over the extensor tendon. The vertical limb of the incision should be carried down beyond the level of the free margin of the web before the transverse circular cut is commenced. If this be done, there will be no difficulty in getting the flaps to meet satisfactorily.

Disarticulation at the metatarso-phalangeal joint of the little toe may be performed by any of the methods applicable to the great toe, employing an external flap, where an internal flap is employed for the latter. As a rule, however, the comparative small size of the parts and the possible distortion of the toe will render the racket method (see p. 280) the most suitable on the whole.

AMPUTATIONS OF THE FOOT

DISARTICULATION THROUGH THE TARSO-METATARSAL JOINTS

This is a very satisfactory form of operation, giving an excellent stump which is fit to bear the full weight of the body and is easily fitted with a suitable boot.

Indications. It is performed fairly frequently, and it may be required for

(i) Severe crushes involving all the toes.

(ii) Some cases of frost-bite limited to the toes, and not implicating the structures in the sole.

For tuberculous disease of the metatarsus, perforating ulcer of the foot, or sepsis limited to the front of the foot, it is, however, not really satisfactory. Tuberculous disease can be better treated either by free exposure and removal of the diseased area, or, if that be impossible, by amputation higher up the limb; a procedure which is certain to remove the entire area of disease, which the disarticulation in question is not certain to do. The same remarks apply to septic conditions about the front of the foot and toes, which can be cured either by properly planned drainage, or by an amputation above the level of the disease. In perforating ulcer of the foot, faulty nutrition of the parts is the primary cause of the ulcer, and this is likely to interfere with union if an amputation be done through the badly nourished tissues.

Three forms of amputation are performed in this situation, of which the true disarticulation is that known as Lisfranc's operation, or separation of the metatarsus from the tarsus, following its anatomical boundaries. The two other operations separate the two portions of the foot more arbitrarily. The operation known as Hey's is a disarticulation through the four outer joints of the foot, followed by removal of the projecting end of the internal (first) cuneiform bone. The third form, known as Skey's, is done by disarticulating the inner and the three outer metatarsals as in Lisfranc's operation, and then sawing across the base of the second metatarsal instead of disarticulating it.

Lisfranc's operation. The operation most in vogue at the present time seems to be Lisfranc's, but the more symmetrical stump resulting from Hey's amputation is, in my opinion, much better than that following the true Lisfranc's, in which the internal (first) cuneiform forms a projection on the inner side of the foot; although this may be useful in bearing the weight of the limb, it nevertheless sometimes offers an obstacle to the proper union of the flaps.

When performing amputation of the metatarsus, I am in the habit of doing the true Lisfranc's operation and then sawing off that portion of the internal (first) cuneiform afterwards that projects beyond the line of the other bones. There is no objection to sawing across this bone; the reason for avoiding doing so in former years, namely, the fear of giving rise to septic osteitis, exists no longer.

Another modification of the amputation which is of practical value in some cases, and which is perhaps the simplest way of performing this operation, is to disarticulate the three outer joints, and then to cut across the base of the second metatarsal and the internal (first) cuneiform with a saw in the line of the three outer articulations. This is a very useful plan should the surgeon find that he has commenced his incisions too far back on the foot, and that he will be unable otherwise to cover the bones efficiently.

Surgical anatomy.. The line of the tarso-metatarsal articulation is an irregular one. It commences on the inner side at the joint between the internal (first) cuneiform and the first metatarsal, and ends at that between the cuboid and the fifth metatarsal on the outer. The projection on the base of the latter bone is easily felt through the skin, and the incision should extend down to the tip of this. The articulation between the internal (first) cuneiform and the first metatarsal on the inner side, however, cannot always be felt, and the best way to localize it is to identify the prominent tubercle of the scaphoid and to take a point a full inch horizontally in front of this; the line of the incision can be determined without difficulty as the shaft of the first metatarsal is easily palpable.

Operation. The surgeon faces the sole of the affected foot and has the limb raised to a suitable height and held with the foot at right angles to the leg by an assistant, who grasps the toes and pulls them backwards. The surgeon defines the anatomical landmarks for his incision, and marks them with his left thumb and forefinger (see Fig. 92). He then enters the point of the knife just below the tip of

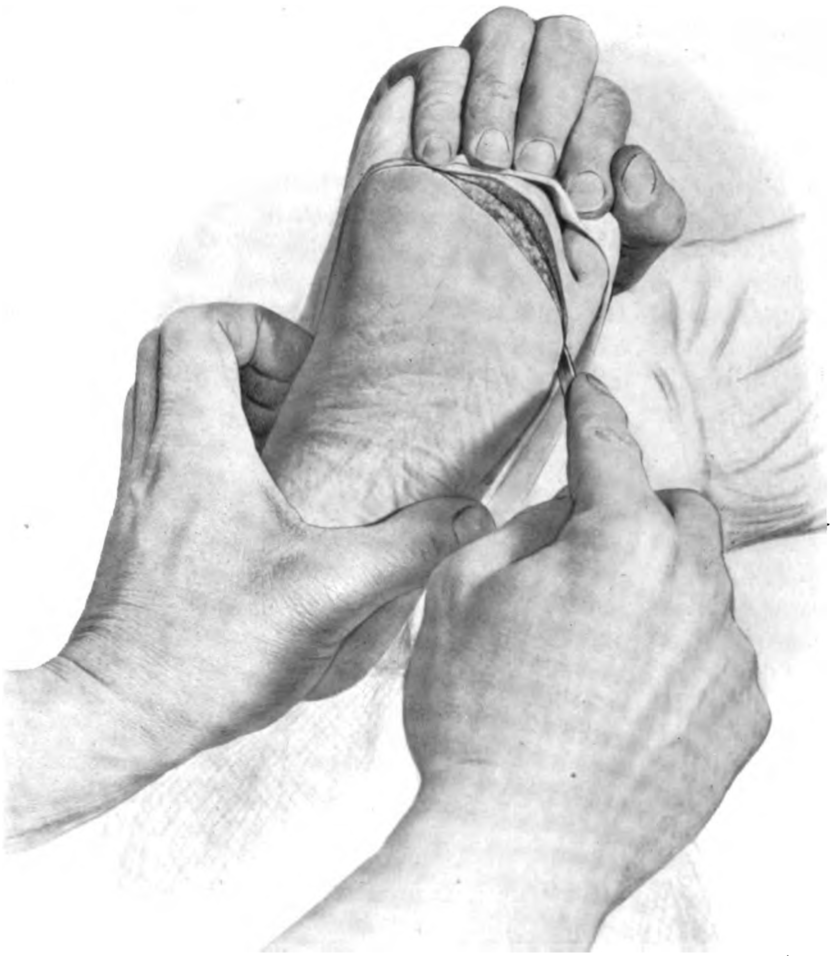

FIG. 92. CUTTING THE PLANTAR INCISION IN LISFRANC'S AMPUTATION. The figure shows the method of marking out the termination of the incision by the left thumb and index finger. It also shows how the foot is held during the incision.

the forefinger, which will be on the outer side of the right limb and on the inner side of the left. From this point the incision is carried forward accurately along the border of the foot until the neck of the metatarsal bone is reached. It is then carried across the sole of the foot over the prominent heads of the metatarsal bones parallel to the line of the web until the opposite border of the foot is reached, when it is carried along that border back to the surgeon's left thumb, which marks the termination of the incision (see Fig. 93).

This incision marks out a large flap on the plantar aspect of the foot which is rather longer on the inner side than on the outer, in order to

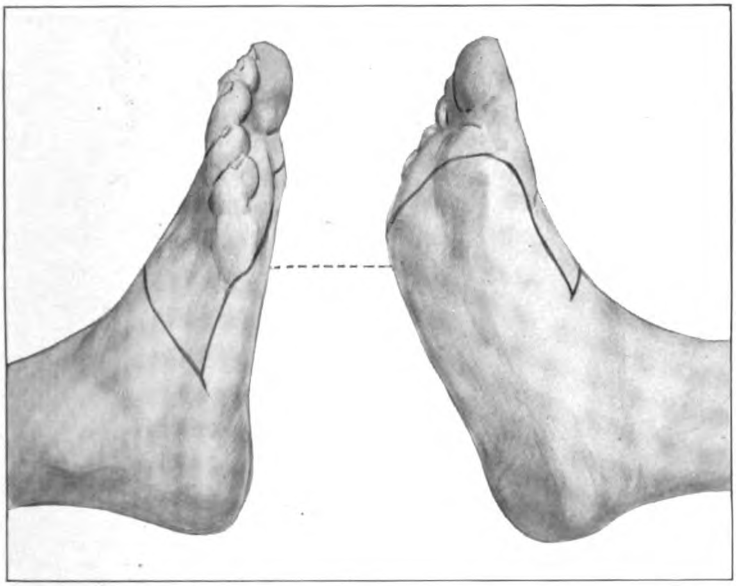

FIG. 93. INCISIONS FOR LISFRANC'S AMPUTATION. The left-hand figure shows the obliquity of the incision from the inner side to the outer side. Note that the horizontal portion of the plantar incision is well up along the respective metacarpal bone.

allow for the due covering of the thicker bones on the inner side of the foot. In making the incision great care must be taken to commence the incision strictly from the anatomical landmarks, especially on the inner side, and to carry it well on the lateral aspect of the foot until the level of the necks of the metatarsals is reached. The tendency is to carry it from the centre of the lateral aspect of the internal (first) cuneiform obliquely into the sole instead of along the inner border of the foot. The knife must be held strictly at right angles to the skin throughout the incision, which should go through the skin and subcutaneous fat only. No tourniquet is needed.

In dissecting up the plantar flap the surgeon raises the skin and fat only for the first inch or so; for this purpose forceps may be used.

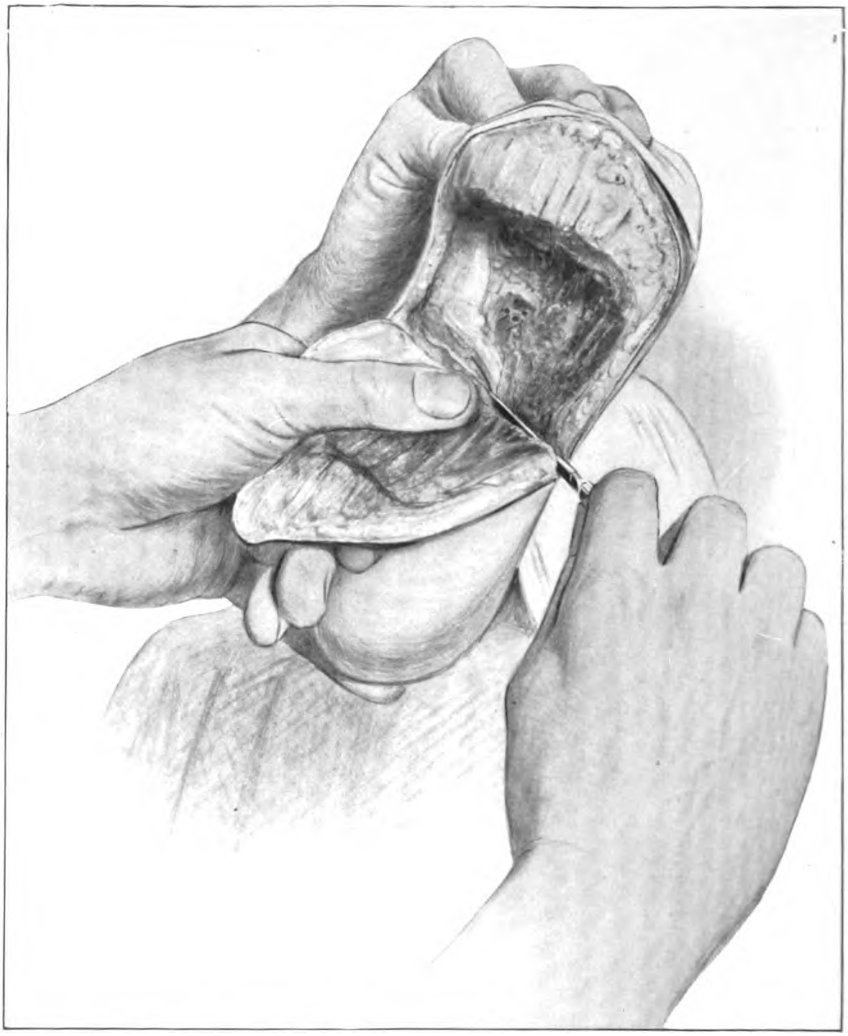

FIG. 94. RAISING THE PLANTAR FLAP IN LISFRANC'S AMPUTATION. All the structures are taken up down to the bone. The large tendon of the peroneus longus can be seen crossing the sole obliquely forwards and inwards from the outer side.

When the level of the necks of the metatarsal bones is reached, however, the edge of the flap is grasped in the fingers and all the structures are taken up down to the metatarsal bones. This gives a large, thick, well-nourished flap which is dissected back to the level of the horns of the incision, when the tendon of the peroneus longus will be seen in its sheath crossing the bones obliquely forwards and inwards (see Fig. 94).

When the plantar flap has been raised sufficiently the surgeon grasps

FIG. 95. METHOD OF GRASPING THE FOOT WHEN CUTTING THE DORSAL INCISION IN LISFRANC'S AMPUTATION. If the surgeon's left hand grasps the foot in this manner it retains perfect control over the front of the foot during the subsequent stages of the operation.

the forepart of the foot with his left hand across the dorsum (see Fig. 95), and joins the two extremities of the plantar incision by a cut across the dorsum slightly convex downwards, extending only through the skin and fascia. When the skin has retracted, the tendons, vessels, and nerves are severed down to the bone on the level of the edge of the retracted skin, and the surgeon proceeds to disarticulate the metatarsus from the tarsus. In the right foot he commences on the outer side, in the left foot on the inner. It is easier to begin from the outer side, as the prominent tuberosity of the fifth metatarsal bone is a landmark that cannot be missed. The knife is slipped in behind it, and, by using the point only, the tarso-metatarsal ligaments are divided, and the two outer joints are opened up with ease as they lie on the same horizontal

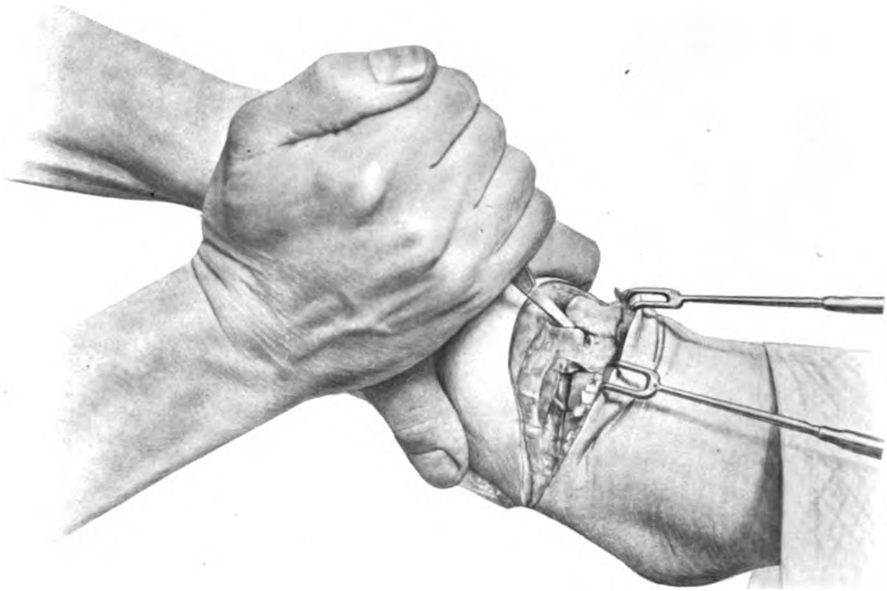

FIG. 96. METHOD OF DISARTICULATING THE BASE OF THE SECOND METATARSAL BONE. The figure shows how the knife is held and introduced between the metatarsal and internal cuneiform.

line. The third joint is also easy to find, but it is a trifle nearer the toes than the two preceding ones.

When these three joints have been opened, the articulation between the first metatarsal and the internal (first) cuneiform must be located and opened. This is the chief stumbling-block of the operation, for, unless the landmarks have been accurately made out, the surgeon may mistake the joint between the scaphoid (navicular) and the cuneiform for that between the latter and the first metatarsal, and may therefore remove the internal (first) cuneiform with the front of the foot. If, however, the three outer joints have been opened first, it is always easy to locate the joint required on the inner side, as it is nearly an inch in front of, viz. nearer to the toes than, the joints just mentioned. When this joint has been opened, all that remains in order to complete the disarticulation is to divide the ligaments of the second metatarsal bone, which is wedged in between the inner and outer cuneiform bones. In order to do this the knife, held as shown in Fig. 96, with its edge upwards is introduced between the first and second metatarsals, and made to find

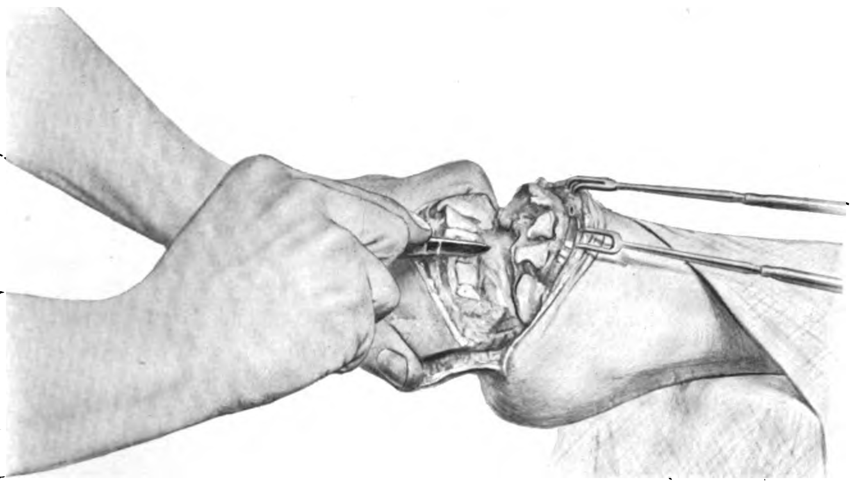

FIG. 97. DISARTICULATION OF THE FRONT HALF OF THE FOOT IN LISFRANC'S AMPUTATION. The knife is in the act of severing the peroneus longus tendon, thereby releasing the front half of the foot.

its way into the interval between them and cut upwards with a light sawing movement. It is then withdrawn and introduced between the second and third metatarsals, where the division of the ligaments is practised in a similar manner. Finally, the ligaments uniting the bone to the second cuneiform are put on the stretch and rendered prominent by pressing the toes downwards, and are divided by a few touches of the point of a knife (see Fig. 96). The foot is thus disarticulated.

Before sewing up the flaps it is advisable to pull out and cut short the tendons on the plantar and the dorsal aspects of the foot. The vessels, namely, the dorsalis pedis and the two plantar trunks, will have been picked up and secured as they were divided in the operation. Should the surgeon desire it, he may finish the operation by sawing off the projecting portion of the internal cuneiform in order to make a neater stump.

When the flaps are brought together their line of union falls upon the dorsal aspect of the limb (see Figs. 98, 99), and the scar will be out

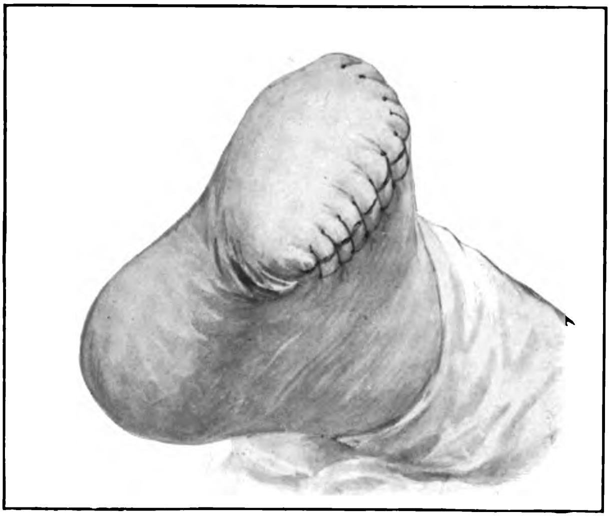

FIG. 98. STUMP OF LISFRANC'S AMPUTATION SEEN FROM THE OUTER SIDE.

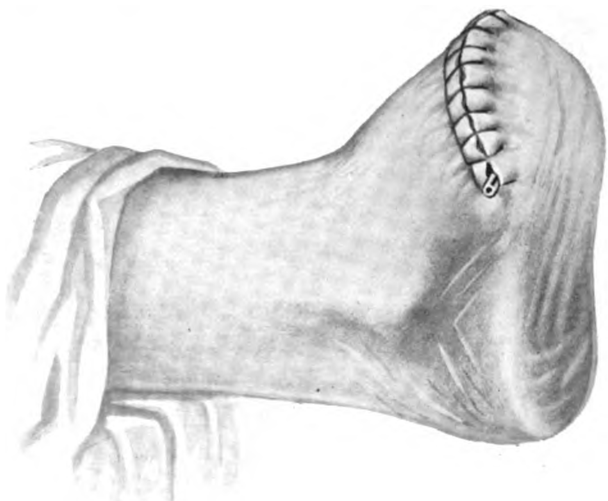

FIG. 99. LISFRANC'S AMPUTATION. STUMP SEEN FROM THE INNER SIDE WHEN THE INCISION HAS BEEN CORRECTLY PLANNED. The line of suture is drawn somewhat up to the dorsal aspect of the foot.

of the way of irritation from pressure owing to the retraction of the skin over the instep. It is important not to cut any dorsal flap; if one be made, the line of union will lie over the edge of the bones, and much distress may ensue from friction against the boot. The plantar flap, on the other hand, is admirably adapted for bearing pressure without trouble. Two drainage tubes should be inserted, one at the inner and one at the outer angle of the stump; this is better than passing a long single tube across from side to side. Stout silkworm-gut sutures will be required to hold the heavy flap in position, and the approximation of the skin-edges should be completed by means of a continuous silk or silkworm-gut suture.

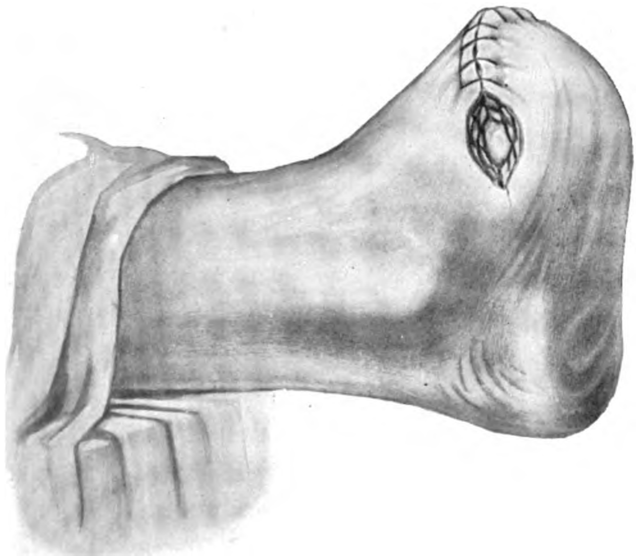

FIG. 100. THE APPEARANCE PRESENTED BY THE STUMP OF A LISFRANC'S AMPUTATION WHEN THE FLAPS HAVE BEEN IMPROPERLY PLANNED. In this case the incision has been begun rather behind the joint on the inner side. The large internal cuneiform is partly exposed and the flaps cannot be properly approximated.

The limb should be put up on a splint with a foot-piece at right angles, and this should be elevated upon a pillow. The knee should be fixed.

After-treatment. The drainage tube should be removed on the third day, when it is an excellent plan to apply a collodion dressing in such a way as to support the heavy flap and prevent the stitches from cutting through (see Fig. 108). The continuous suture may be removed at the end of ten days, but the deep silkworm-gut sutures should not be dispensed with for at least a fortnight or three weeks from the time of operation. The patient is usually able to bear a fair amount of pressure upon the limb in about a month's time, and the stump should be perfectly sound and useful in six weeks, as the skin covering the sole ought to bear any pressure thrown upon it without injury.

Difficulties. The most serious difficulty is a mistake in locating the landmarks when cutting the flaps; in operating upon the cadaver this mistake is constantly made. It is somewhat easier to define the points in the living subject, but even then there is a liability to go wrong, unless care be taken to place the thumb or forefinger on each point as it is identified, and to keep them in position until the incision marking out the plantar flap has been completed.

Another serious difficulty has already been referred to, namely, the inability to cover the inner aspect of the internal (first) cuneiform (see Fig. 100); this is due to the incision either being commenced well below the level of the centre of the lateral aspect of the first metatarsal, or else being carried down on to the sole too quickly, instead of running horizontally along the lateral aspect of the metatarsal.

The third difficulty, namely, the disarticulation of the second metatarsal bone, has also been referred to (see p. 288), and can be avoided by following the instructions there given. It is, however, chiefly a difficulty of the examination room, for, in actual practice, it makes no difference whatever whether the bone be cleanly disarticulated or its base sawn across and left behind.

DISARTICULATION AT THE MEDIO-TARSAL JOINT

Chopart's amputation. This operation, which is still a favourite at examinations and in the dissecting room, is of little value in practice; it does not compare for usefulness with Syme's or some form of the sub-astragaloid amputation. The objections to Chopart's amputation are numerous, the most important being that, owing to the removal of the front of the foot, the body weight ceases to be transmitted through the heads of the metatarsal bones, and so the astragalus (talus), through which the weight is transmitted, loses the support afforded it by the front of the foot in the normal state, and tends to be thrust forward beneath the tibia against the cicatrix, to which it becomes adherent, so that a painful ulcerated stump results. Moreover, the tendo Achillis causes tilting of the heel, since its action is unbalanced by the dorsiflexors of the foot, such as the tibialis anticus (anterior) and the extensors. This tends to protrude the astragalus (talus) still further, and is practically impossible to remedy. Division of the tendo Achillis is only of temporary benefit, and even the suggested implanation of the dorsi-flexors of the foot into the plantar flap does not provide them with sufficient leverage to enable them to act satisfactorily.

Quite apart from the unsuitability of the stump, there is the further objection that the scope of the operation must necessarily be very limited. In cases of injury it will generally be possible to preserve some portion of the cuneiform bones at any rate, and so to secure a foot that will be more mechanically useful; this means that some modification of Lisfranc's amputation (see p. 283) will be preferred. In tuberculous or septic disease Chopart's operation is wholly unsuitable; owing to the arrangement of the synovial membrane, tuberculous disease which has spread as far as the scaphoid (navicular) and the cuboid will have extended to the tendon sheaths in the vicinity, or to the joints on the

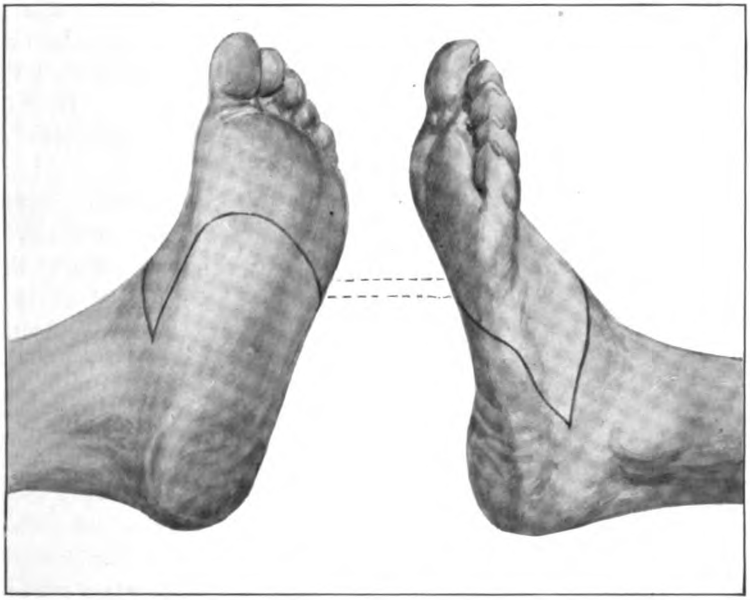

FIG. 101. INCISIONS FOR CHOPART'S AMPUTATION.

proximal side of the medio-tarsal articulation, and some more radical operation which will ensure removal well beyond the limit of the disease must be practised. The same remark applies to septic disease.

Surgical anatomy. The only prominent guide to the joints between the os calcis (calcaneus) and the astragalus (talus) behind and the cuboid and the scaphoid (navicular) in front, is the tubercle of the latter, which is about half an inch in front of the joint on its inner side. On the outer side the joint lies about midway between the tip of the external malleolus and the tuberosity and the fifth metatarsal bone. The line of the joint is almost transverse, the calcaneo-cuboid articulation being on a slightly posterior level to the astragalo-scaphoid (talo-navicular).

Operation. The foot is raised and somewhat dorsi-flexed by an assistant; the surgeon stands facing the sole. The left thumb and forefinger are placed upon the two anatomical landmarks mentioned above, and a plantar flap is marked out commencing on the outer side of the right foot and on the inner side of the left (see Fig. 101). The incision resembles that for Lisfranc's operation (see p. 283), except that it does not extend as far forwards as the level of the necks of the metatarsal bones; as in Lisfranc's, it is longer on the inner side than on the outer, and the same care must be taken to keep it well up on the inner and outer borders of the foot respectively, or else it will be difficult to cover the bones at the junction of the flaps. The plantar flap is raised just as in Lisfranc's operation (see p. 283), the skin and subcutaneous fat being taken for the first inch, and after that all the soft parts down to the bones.

When the flap has been raised as far back as its base, the foot is grasped across the dorsum, depressed forcibly, and a dorsal incision marked out by joining the two ends of the plantar incision across the front of the instep. This incision should only have a very slight convexity downwards, as it is important that the cicatrix should lie upon the dorsum of the foot, so as to be well out of the way of injurious pressure; therefore no pronounced dorsal flap must be cut. At the first incision the skin alone is divided, and when this has retracted, the remaining soft parts, tendons, &c., are divided down to the bone at the level of the edge of the divided and retracted skin.

In order to disarticulate, the tubercle of the scaphoid (navicular) is identified, and the point of the knife is inserted into the joint immediately behind it. As the two joints forming the medio-tarsal articulation are nearly on the same level, disarticulation can usually be completed from the side upon which it was begun; if not, it must be remembered that the level of the calcaneo-cuboid articulation is slightly behind that of the astragalo-scaphoid (talo-navicular). The subsequent steps are similar to those of Lisfranc's operation (see p. 283). The operation should be concluded by fixing the extensor tendons to the front of the bone or to the large plantar flap by any form of suture that seems most suitable at the time.

Some surgeons complete the operation by dividing the tendo Achillis; this, however, can only be of temporary benefit, and it is hardly worth while performing it, provided that due care be taken to obviate pain and spasm by suturing the flaps securely and avoiding undue pressure on the end of the stump. A splint should be employed similar to that for Lisfranc's operation, and the foot should be put up and maintained strictly at right angles to the leg. A large pad of dressing may be put beneath the front of the stump in order to tilt that end of the foot up, and several stout silkworm-gut sutures should be used to keep the flap in position, in addition to a continuous suture for apposition of the skin edges.

The operation gives an excellent looking stump, and does not shorten the limb, so that the immediate result is all that could be desired. In a short time, however, tilting of the stump occurs, and with it comes pain and irritation of the scar.

Tripier's operation. There is a modification of this operation that goes by the name of Tripier, which consists in removing the lower half of the os calcis (calcaneus), in addition to amputating at the medio-tarsal joint. There does not seem to be any practical advantage in this operation that is not to be found in other and better operations. Its chief object seems to be to provide horizontal under-surface to the os calcis (calcaneus) instead of an oblique one; thus, it resembles somewhat a sub-astragaloid amputation, which, however, has the great advantage over Tripier's that it cannot be spoiled by the baneful influence of the tendo Achillis. The difference in the amount of shortening after Tripier's operation and after a sub-astragaloid amputation is so slight as to be negligible. It will not be necessary to describe Tripier's operation in detail.

SUB-ASTRAGALOID DISARTICULATIONS

By this term is meant an amputation that removes all the bones of the foot below the astragalus, leaving that bone with its connexions to the tibio-fibular arch undisturbed. Several forms of this operation have been suggested, and they all have for their object the provision of a stump calculated to bear firm pressure, while shortening the limb less than Syme's amputation. The patient walks upon the part of the sole that he normally uses for locomotion, and bears his weight upon the whole width of it instead of upon the narrower surface furnished by Syme's amputation. The joint between the astragalus (talus) and the tibio-fibular arch is retained and is of distinct value. Lastly, there is less risk of damage to the blood-supply of the flap, a not inconsiderable advantage to those performing the operation for the first time. The stump thus provided has none of the inconveniences, such as tilting of the heel, that are so often met with after Chopart's amputation. The weight is borne upon the under-surface of the astragalus, which supports pressure well. In order to leave a perfectly level surface for the weight to be borne upon, some surgeons saw the astragalus horizontally; but, although theoretically good, this does not offer any practical advantage and is unnecessary, especially as it shortens the limb and prolongs the operation. The stump is an excellent one, and is easy to fit with an artificial foot. The operation is becoming more popular than it was, but it still is not practised as often as its great merits entitle it to be. The steps of the operation are a little difficult to remember at first, but, once mastered, the operation will be favourably viewed by any one who practises it. Various modifications of the operations are given in the following pages, but the form that gives the best results on the whole, and the one that should be employed whenever the condition of the soft parts allows, is that associated with the name of Farabeuf. In order to per-

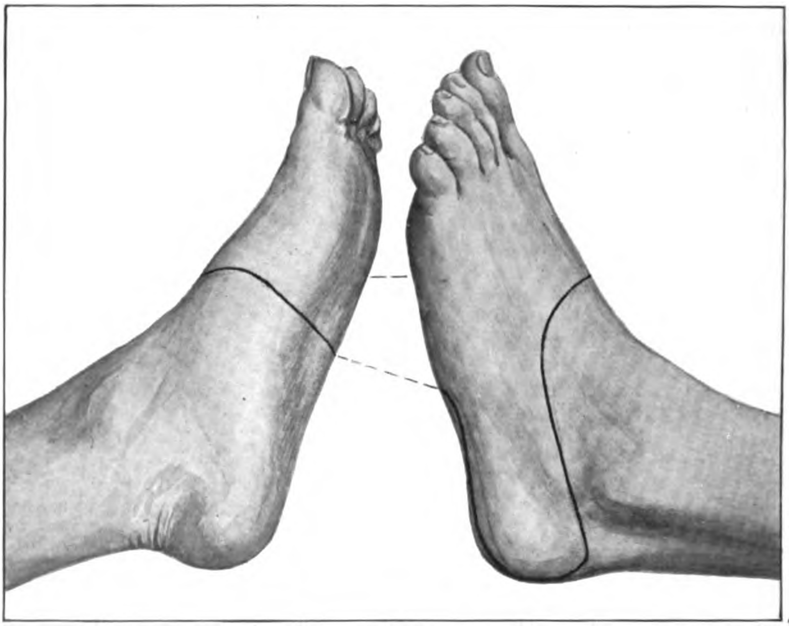

FIG. 102. INCISIONS FOR FARABEUF'S SUB-ASTRAGALOID DISARTICULATION.

form it safely the tissues of the foot must be sound as far forward as the level of the tarso-metatarsal articulations. It is done as follows:—

Farabeuf's operation. The limb is brought over the end of the table, raised and somewhat inverted. It is not absolutely essential to apply a tourniquet to the thigh, but it is wise to do so, as bleeding points are difficult to pick up as they are met with. The surgeon stands facing the sole and marks out a large internal flap by an incision which starts from the outer margin of the heel, runs parallel to the outer border of the foot, a finger's breadth below the tip of the external malleolus, and is carried horizontally forward to the level of the tuberosity of the fifth metatarsal; it then curves sharply inwards across the dorsum just in front of the joint between the scaphoid and the three cuneiform bones until the tendon of the extensor hallucis longus is reached. The object of this curve in the flap is to cover the neck and head of the astragalus. From the extensor hallucis longus tendon the incision passes across the inner border of the foot, with a well-marked convexity forwards, beneath the arch of the instep to the centre of the sole. From this point the incision slopes gradually back to the outer border of the foot close behind the tuberosity of the fifth metatarsal, and from this point is carried back horizontally just above the outer border of the sole to the external tuberosity of the os calcis, where it curves upwards to join the commencement of the incision (see Fig. 102). These two incisions, the horizontal and the vertical one, meet nearly at a right angle near the outer border of the tendo Achillis, just at its insertion into the os calcis.

Farabeuf (*Manuel Opératoire,* 1895, p. 519) gives the following practical instructions as to cutting the flaps, which may be reproduced here with advantage in view of the great practical usefulness of the operation. The steps vary according as the left or right foot is to be operated upon.

Left Foot. The front of the foot is seized in the left hand, depressed, and rotated inwards. The incision is then begun over the prominence of the tendon of the extensor hallucis longus, just in front of the articulation of the scaphoid with the cuneiform bones. The incision, which should go down to the bone, is carried transversely outwards from this point for about five cm. (two inches) in the direction of the tuberosity of the fifth metatarsal. From this point it is carried backwards, parallel with the outer border of the foot and passing a full finger's breadth beneath the external malleolus to the outer border of the tendo Achillis just at its insertion into the os calcis.

The assistant now raises the limb so that the sole faces the operator. The front of the foot is raised and rotated outwards with the left hand, and the knife is made to enter the commencement of the dorsal incision over the tendon of the extensor longus hallucis. From this point the incision is brought downwards to the sole with a slight convexity forwards, so that it crosses the inner border of the foot just beyond the articulation between the first metatarsal and the internal (first) cuneiform. Thence the knife is drawn transversely across the sole to about its mid-point (see Fig. 103), and is then curved backwards to the outer border of the foot, which it follows backwards as far as the outer tuberosity of the os calcis, being finally carried upwards behind the heel to the outer border of the tendo Achillis to join the posterior end of the first incision. In doing this, the foot has to be raised considerably. The incision is carried down to the bone throughout, and is best made with a short stout knife having a cutting blade of not more than two or three inches, so as to diminish the chance of the knife slipping.

Fig. 103. Cutting the Plantar Portion of the Incision on the Left Foot in Farabeuf's Sub-astragaloid Disarticulation. The figure shows how the foot is grasped in the surgeon's left hand and is rotated over towards his right so as to make the inner aspect of the foot accessible to the knife.

In order to perform disarticulation in the easiest manner, the assistant bends the knee at right angles and rotates the foot forcibly inwards, at the same time fixing the lower end of the leg firmly upon the table. The upper part of the incision is now deepened down to the bone throughout, so as to divide all the tendons, and the short upper and outer flap is raised, cutting close to the bone throughout. This exposes the head of the astragalus, which is made more prominent by pressing the front of the foot downwards, and the articulation between the

FIG. 104. SEPARATING THE OS CALCIS FROM THE ASTRAGALUS IN FARABEUF'S SUB-ASTRAGALOID DISARTICULATION. The knife is being drawn from left to right; it has divided the interosseous ligament between the os calcis and the astragalus and is proceeding to divide the tendo Achillis at the extreme right.

scaphoid and the astragalus can be opened by a few touches of the knife. The point of the knife is now introduced beneath the head of the astragalus, and, cutting backwards, divides the interosseous ligament, a manœuvre that is aided by pressing firmly upon the outer surface of the os calcis. When the interosseous ligament has been divided, the parts become more accessible, and the foot is bent still further downwards, so that the upper surface of the os calcis faces the operator. The knife is carried back, and, after dividing the remainder of the calcaneo-astragaloid (talo-calcaneal) ligaments, reaches the tendo Achillis, which is divided just above its insertion (see Fig. 104).

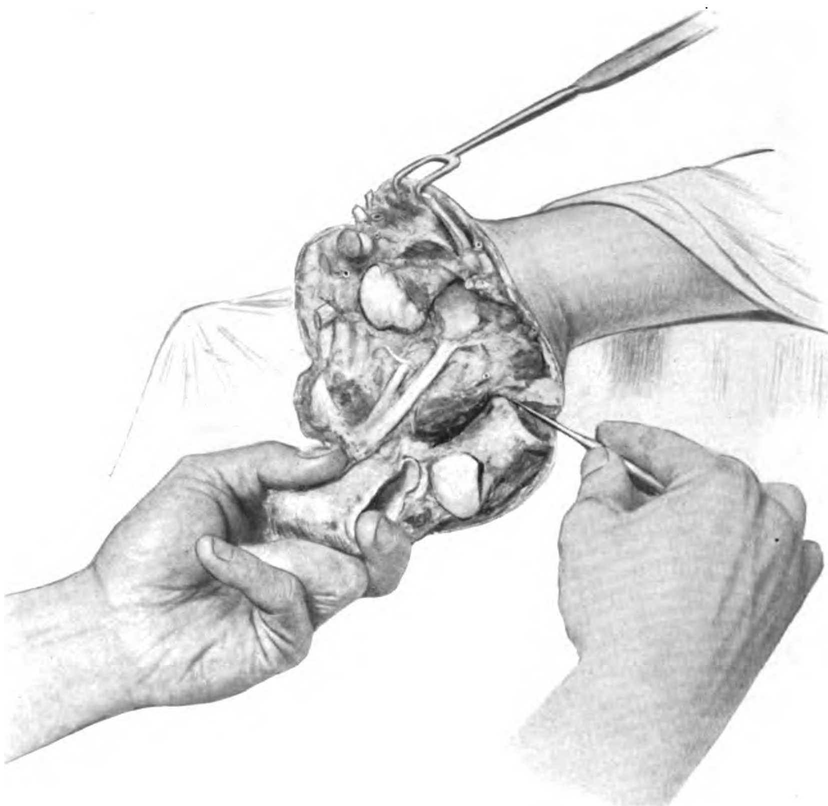

FIG. 105. THE FINAL STAGES OF CLEARING THE OS CALCIS IN FARABEUF'S SUB-ASTRAGALOID DISARTICULATION. The os calcis and front of the foot are rotated so that the upper articular surface looks directly towards the operator and the inner surface looks vertically upwards. The structures have been turned out from beneath the sustentaculum tali and the knife is completing the removal of the foot by a few touches at the back of the os calcis.

The more difficult part of the operation is now undertaken, viz. separating the large internal flap from the inner side of the foot, as the irregular surface presented by the tuberosity of the scaphoid, the sustentaculum tali, and the hollow of the os calcis exposes the vessels and nerves which lie in close contact with them to some risk of damage.

Only the point of the knife should be used, and it is important to keep the foot horizontal, and to cut as close to the bone as possible. As the foot is freed it is pulled forwards horizontally from the leg. The first step is to divide the tibialis posticus from the scaphoid, and then, passing backwards, to cut the fibres of the internal lateral ligament attached to that bone and to the sustentaculum tali; this must be done with the point of the knife, and great care must be taken not to cut deeply into the flap beyond. The knife is then held very obliquely so as to be parallel to the course of the plantar vessels, and, with the cutting edge closely applied to the bone throughout, it is swept along the wound, from before backwards, until it is behind the os calcis. This is done several times, and, when the sustentaculum tali has been laid bare, the structures in the groove beneath it are turned out carefully, and finally the muscles attached to the tuberosity of the os calcis are divided. The division of the tendo Achillis is completed, and the foot is rotated more and more outwards around its antero-posterior axis until the outer border of the os calcis is cleared, and the flap is freed (see Fig. 105).

Right Foot. The front of the foot is seized with the left hand, depressed and the limb rotated inwards. The incision is commenced over the outer border of the tendo Achillis, and carried horizontally forwards a finger's breadth below the external malleolus as far as the level of the tuberosity of the fifth metatarsal, when it is curved inwards almost transversely across the front of the instep to the tendon of the extensor hallucis longus. The foot is now rotated outwards, and the dorsal incision is continued, with a convexity forwards, across the inner side of the foot, which it crosses about its centre. The assistant then raises the limb, the surgeon pushes up the front of the foot and the incision is carried across to the centre of the sole, whence it is curved back to the outer border, which it follows to the external tuberosity of the os calcis, where it is curved upwards to meet the commencement of the incision. I have always found it more convenient to trace out the last part of this incision in the reverse direction, *i.e.* from the outer tuberosity of the os calcis along the outer border of the foot, after rotating the foot inwards again.

The position for disarticulation is the same as in the preceding case, that is to say the knee is flexed to a right angle and rotated fully inwards and the assistant fixes the lower end of the tibia and fibula firmly on the table so that the outer border of the foot is horizontal. The calcaneo-astragaloid articulation is opened from behind forwards and the interosseous ligament divided. This is rather more difficult than on the opposite side, but firm pressure on the outer border of the foot will give room enough to allow the point of the knife to effect the division. The remainder of the operation is similar to that on the opposite side, except that the incision here has to be carried from behind forwards, namely, from the insertion of the tendo Achillis to the astragalo-scaphoid joint. The same care must be taken of the structures beneath the sustentaculum tali.

After the operation any tendons showing in the flap are cut short, especially that of the tibialis posticus (posterior) (see Fig. 106). The posterior tibial nerve is similarly treated; in doing this, care must be taken not to damage the corresponding artery. Few vessels of importance require ligature; they are the dorsalis pedis and the two plantar arteries.

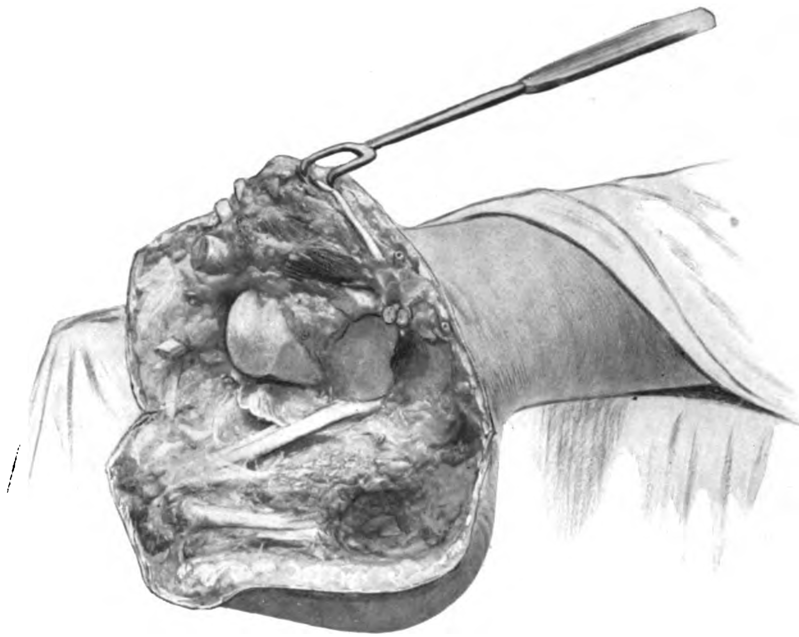

FIG. 106. THE APPEARANCE OF THE FLAPS AFTER FARABEUF'S SUB-ASTRAGALOID DISARTICULATION. The inferior articular surfaces of the astragaloid are well seen, as is the tendon of the tibialis posticus; the cavity out of which the posterior part of the os calcis has been dissected also shows well.

When the flaps are brought together (see Fig. 107) they will cover the head of the astragalus satisfactorily, if attention has been paid to the instructions given above. The tendency, however, is to carry the incision across the inner side of the foot too obliquely backwards, and this may interfere with the proper covering of the head of the astragalus. If the flaps cannot be made to meet, it will be necessary to cut down the head of that bone until the flaps cover it satisfactorily. Farabeuf advises that the extensor tendons should be sutured to the flap, but this is not a point of great importance. Good drainage is necessary, and may be effected by making a button-hole on the posterior aspect of the stump, and inserting a drainage-tube about the size of the little finger. This drains the large cavity left by the os calcis; a good result can be obtained, however, by a large tube inserted in the posterior end of the incision. The flaps are coapted by six or eight stout silkworm-gut sutures inserted deeply through the tissues, and reinforced by a continuous suture of fairly stout silk or silkworm-gut.

An ordinary stump bandage should be applied, and fairly firm pressure exerted over the end of it so as to obliterate the cavity made by the flaps. Farabeuf recommends that the knee should be bent, and the

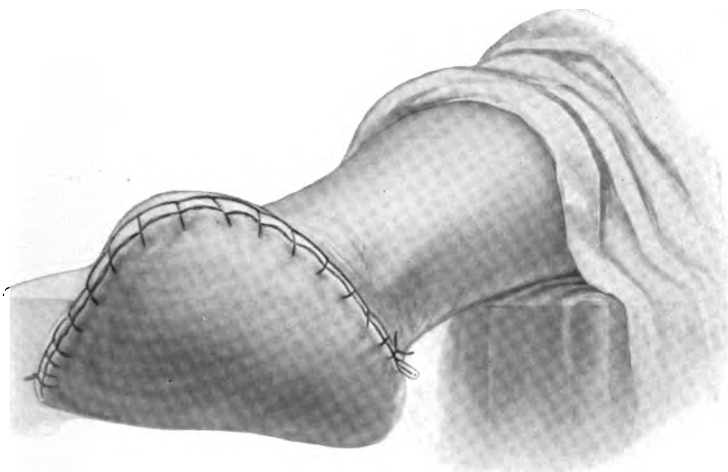

FIG. 107. STUMP LEFT AFTER FARABEUF'S SUB-ASTRAGALOID DISARTICULATION. In this instance the drainage tube has been inserted in the posterior end of the wound. For drainage in fat subjects it is certainly better to puncture the cavity left by the removal of the os calcis at its most dependent spot.

limb laid upon its outer side. If this be done, the limb should be immobilized by being laid between sand-bags, as otherwise painful startings of the stump are likely to occur. No splint is necessary.

The stump should be dressed at the end of three days, and the drainage tube removed. At this time it is well to fasten on the under dressings with collodion, which should be applied as shown in Fig. 108, so as to press the flaps firmly together. The deep sutures should remain undisturbed for a fortnight or three weeks, unless they cause irritation. The superficial continuous suture may be taken out on the tenth day. The flaps are supported by a firm bandage, and the patient may begin to bear pressure upon the stump in about a month, and may be fitted with an artificial foot in about six or eight weeks' time.

The advantage of Farabeuf's operation lies not only in the excellence of the resulting stump, an example of which is seen in Fig. 107, but in the ease with which disarticulation is performed. The chief difficulty for a beginner is to remember the incision, which, however, soon disappears when the operation has been practised a few times on the dead subject. The operation can be done rapidly and is not nearly so tedious as a Syme. It is easier to perform than any other sub-astragaloid disarticulation with which I am acquainted, and it should therefore be made use of whenever the condition of the soft parts permits. It may happen, however, that the tissues on the inner side of the foot are not sound

FIG. 108. METHOD OF APPLYING DRESSING TO THE STUMP OF FARABEUF'S SUB-ASTRAGALOID DISARTICULATION. If the dressing be first applied to the hinge-side of the flap and brought firmly across it as shown in the drawing, it helps to keep the flap well in position.

enough to warrant it being done in all the cases in which a sub-astragaloid disarticulation is considered desirable, and therefore the reader should familiarize himself with modifications of this most useful operation. The following are the principal:—

Nélaton's operation. The incision is begun near the posterior end of the outer surface of the os calcis near its upper border, and carried forward a finger's breadth below the external malleolus nearly as far as the tuberosity of the fifth metatarsal bone. It then curves across the dorsum of the foot with its convexity forwards and runs somewhat backwards to the tuberosity of the scaphoid, whence it is carried downwards and forwards, crossing the inner border of the sole on a level with the fifth metatarsal bone, and is finally carried right across the sole on that level so as to form a plantar flap with its convexity forwards. When it reaches the outer border of the foot it is carried back to its starting-point (see Fig. 109). The resulting flaps form a compromise between an antero-posterior flap and a racket amputation. Disarticulation is effected from the outer side, but is much hampered by the want of room, and the incision may have to be prolonged backwards over the tendo Achillis.

Roux's operation. This operation is hardly as satisfactory as the others, since it provides less suitable covering for the head of the astragalus. It commences at the outer tuberosity of the os calcis and is

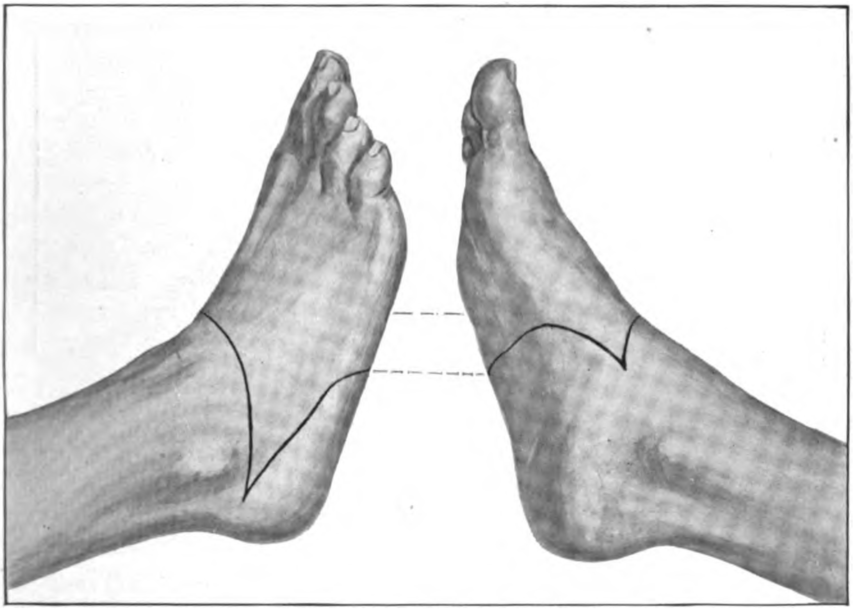

FIG. 109. INCISIONS FOR NÉLATON'S SUB-ASTRAGALOID DISARTICULATION.

carried horizontally forwards to the level of the base of the fifth metatarsal bone. Thence it runs across the instep with a slight convexity forwards to the middle of the inner surface of the internal cuneiform. From this point it curves backwards across the sole and round the outer border of the foot to its point of origin.

Racket incision. This is a simple and fairly satisfactory method, but the dissection required during disarticulation is more tedious than in Farabeuf's operation. The incision is carried horizontally forwards from the outer border of the insertion of the tendo Achillis, a full inch below the external malleolus, to the level of the prominence of the fifth metatarsal bone. Thence it is carried across the instep with a slight convexity forwards and crosses the inner border of the foot on a level with the articulation between the first metatarsal and the internal cuneiform bones. It then traverses the sole with a slight convexity forwards, and is carried back to join the horizontal incision about one inch behind the base of the fifth metatarsal (see Fig. 110).

This incision facilitates the division of the tendo Achillis, but the flaps have to be raised very freely before disarticulation can be under-

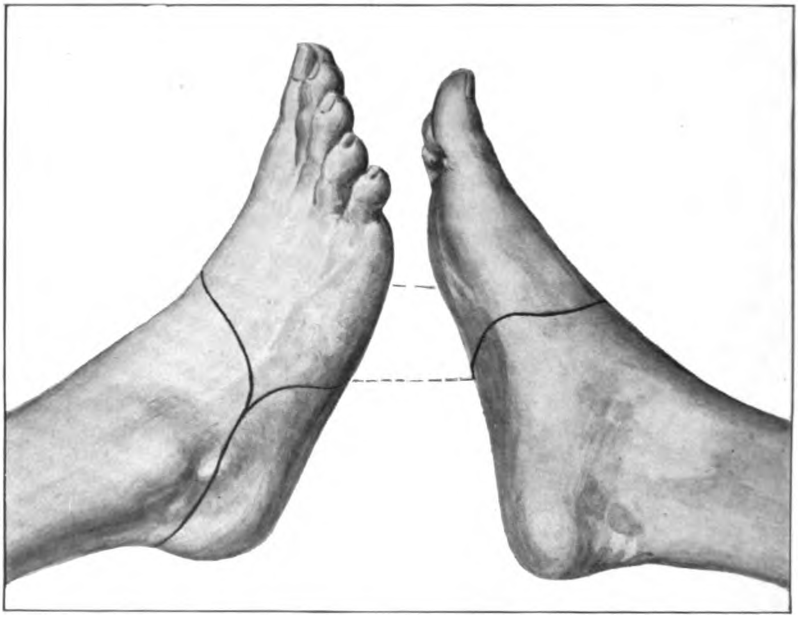

FIG. 110. RACKET INCISIONS FOR SUB-ASTRAGALOID DISARTICULATION.

taken, owing to the less free exposure of the parts. The important structures on the inner aspect of the foot are in greater danger of being wounded than in Farabeuf's method.

DISARTICULATION AT THE ANKLE-JOINT

Syme's amputation. The most useful type of this form of amputation is that known as Syme's, in which the amputation is done by means of a large heel flap. The operation is not a true disarticulation, inasmuch as the two malleoli are removed at the same time in order to obtain a level surface upon which the patient may bear his weight.

Indications. (i) The operation is an excellent one for an *injury* in which the soft parts of the foot are damaged so far back that the sub-astragaloid disarticulation is not feasible.

(ii) For *disease* it will be rarely resorted to, the only affection for which it is likely to be really successful being a growth of the foot not involving the skin. In cases of tuberculous ankle-joint disease beyond the reach of cure by arthrectomy, the mischief will almost invariably have spread to the tendon sheaths, and the surgeon will be better advised, when he has decided that the disease is not likely to be cured by a careful and extensive arthrectomy accompanied by excision of the astragalus, to amputate above the ankle-joint. In gangrene of the lower extremity the defective blood-supply of the parts about the ankle will preclude its choice, whilst in septic infections that are not amenable to free incisions and drainage, amputation through the leg will probably also be the wiser course.

(iii) It may be used in cases of inveterate *talipes* due to infantile paralysis accompanied by trophic disturbances of the toes and front part of the foot. As this operation shortens the limb considerably and also provides a heel flap of doubtful vitality, some form of sub-astragaloid amputation or a trans-calcaneal operation is likely to prove more generally useful for these cases.

Operation. The foot is made to project well beyond the table and is held by an assistant with the toes pointing directly upwards so that the sole faces the operator; the foot should be on a level with the surgeon's face whether he be sitting or standing. It is usual to do the operation sitting down, when the plantar flap is raised from below; when, however, the flap is dissected up after disarticulation from above, it is done standing up, and on the whole it is better to perform the operation in that position. The surgeon faces the sole and places his left thumb and index finger upon the two ends of the incision for the heel flap, which extends from the tip of the external malleolus to a point about half an inch vertically below the tip of the internal malleolus; when doing this the left hand is placed over the dorsum of the foot. In the left foot the incision commences on the outer side, whilst in the right foot it commences on the inner side. This incision runs down almost vertically across the sole (see Fig. 111); in ordinary subjects it should have a slight inclination backwards towards the point of the heel, but a marked one in those in whom the heel is large and prominent. It is important to see that the foot is strictly at right angles to the leg while the incision for the heel flap is being made. If this precaution be neglected and the toes be depressed, an incision, apparently running vertically downwards, really is directed obliquely forwards towards the toes, and the result is a large unwieldy heel flap that cannot be raised satisfactorily.

The incision is made by entering the point of the knife at the starting-point of the incision and carrying it down to the bone at once. The knife is then drawn across the sole with a steady sawing movement, and is made to divide all the soft structures right down to the

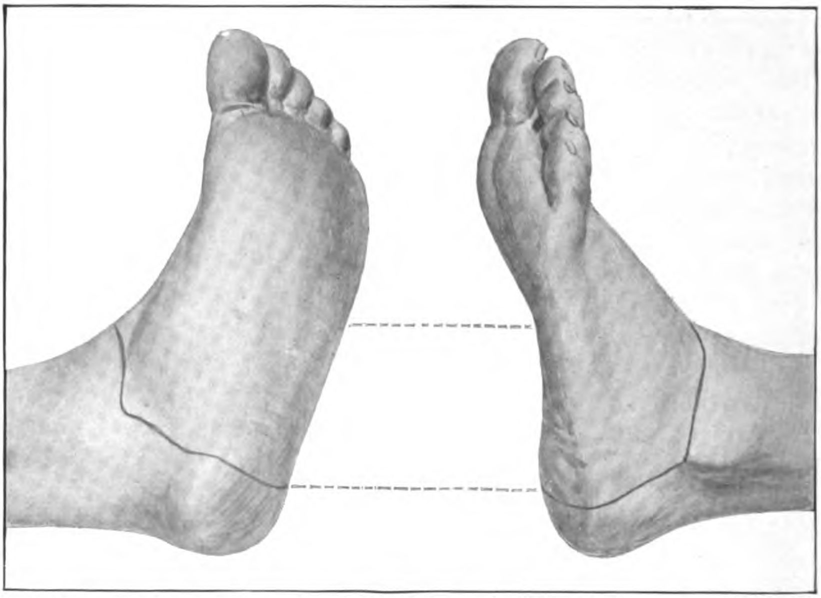

FIG. 111. INCISIONS FOR SYME'S DISARTICULATION AT THE ANKLE-JOINT.

os calcis at the first incision. As the knife nears the finishing point of the incision, great care must be taken that it does not slip, and it is well to use the special knife introduced by Syme, and known as Syme's foot knife (see Fig. 112). Unless the surgeon be very expert it is best to trace out only the first two-thirds of the incision and then to re-introduce

FIG. 112. SYME'S FOOT KNIFE.

the knife at the true point of termination, and cut downwards until the original incision is joined. A slip of the knife when terminating the incision is especially apt to be disastrous on the inner side, where the posterior tibial vessels may be wounded and the blood-supply of the flap seriously damaged.

The next step in the operation as recommended by Syme is to raise the heel flap from the back of the os calcis (calcaneus) by dissection; this is a tedious and difficult procedure, and the operation can be much simplified by disarticulating from the front and dissecting the os calcis out of the flap instead of dissecting the flap off the os calcis.

Should the surgeon desire to raise the heel flap by dissection, however, he proceeds to do so by a series of short strokes, cutting steadily on the bone and using only the point and the terminal half-inch of the blade of the knife, commencing on the left-hand side of the limb as he faces it and working from left to right. As the flap is freed it is forced back by the left thumb, which serves to protect it from damage by the knife. Particular care must be taken to avoid damaging the posterior tibial vessels which lie in close proximity to the incision on the inner side. As soon as the flap has been freed in this situation it is a good plan to insert a flat retractor between the vessels and the bone, and to give this to an assistant, who thus keeps the vessels guarded from harm during the remainder of the operation.

The flap is gradually dissected up from the inferior and posterior surfaces of the os calcis as far as its upper border, the foot being raised by an assistant during the process. The tendo Achillis is not cut at this stage. It is practically imperative that the surgeon should sit during this very tedious part of the operation, but when the flap has been freed he stands up, grasps the foot in his left hand as shown in Fig. 95, and joins the two extremities of his first incision by a straight cut across the front of the ankle-joint, dividing the skin and fascia only. Before this incision is made, the line of the ankle-joint should be ascertained by flexing and extending the limb, as otherwise the incision may be too low and the astragalo-scaphoid (talo-navicular) joint may be opened by mistake. The tendons and the anterior ligament of the ankle-joint are now divided on a level with the edge of the divided skin, and then the remaining fibres of the lateral ligaments are divided by the point of the knife, which should be inserted beneath them—namely, between them and the bone—and made to cut outwards. The heel flap is held back out of the way while this is being done. Disarticulation is completed by dividing the posterior ligament and the tendo Achillis.

A much less tedious method is to make the dorsal incision immediately after the plantar and to effect the disarticulation from the front. After the surgeon has made the dorsal incision with the precautions given above, he divides the extensor tendons and opens the ankle-joint. The toes are now depressed and the lateral ligaments divided, the internal first, by inserting the point of the knife between them and the bone and cutting outwards. As the ligaments are divided, the upper surface of the astragalus is rendered prominent by depressing the toes forcibly, and the knife divides the posterior ligament of the ankle-joint and the tendo Achillis, and dissects the back part of the os calcis out of the soft parts forming the heel. This dissection must be done with every precaution against damaging the vessels and nerves on the inner side just behind the junction of the dorsal with the plantar flap. There is no risk of wounding these structures if only the point of the knife be used and every cut be made directly down upon the bone. The most difficult part of the operation is dissecting the back part of the os calcis out of the heel, owing to the intimate connexion of the soft parts with the underlying bone. It is facilitated by pushing the point of the heel firmly forward with the first two fingers of the left hand, which grasps and manipulates the foot throughout the disarticulation.

After disarticulation, the soft parts are dissected up for a short distance from the lower end of the tibio-fibular arch so as to facilitate the removal of the malleoli. The soft parts need only be detached for about a quarter of an inch up from the articular edge, but care must be taken to see that the heel flap is not doubled upon itself and button-holed while this is being done. The saw is applied to the base of the malleoli so as to remove them, and with them just enough of the cartilage-covered surface of the tibia to furnish a horizontal surface upon which the patient's weight can be borne. It is unnecessary to remove the whole of the cartilage of the tibio-fibular arch.

The final steps of the operation are ligature of the vessels, viz. the dorsalis pedis in the front flap and the two plantar arteries on the inner side of the heel flap, and the removal with scissors of any tendons visible on the stump; a portion of the posterior tibial nerve should also be removed. The heel flap is punctured about its centre and a small drainage tube is inserted through it. The flap is then secured in position by four stout silkworm-gut sutures introduced deeply and reinforced by a continuous stitch for the coaptation of the skin edges. The dressings are applied first along the back of the leg and then stretched across the end of the stump and carried up along the front of the leg so as to press the flap firmly in contact with the lower end of the bones. The method of dressing and after-treatment are practically identical with that for the sub-astragaloid disarticulation (see p. 303).

Results. The stump is one of the best known to surgeons. It is firm and will stand any reasonable amount of pressure, and the patient can run and jump without difficulty. He can generally begin to bear pressure on it in about six weeks, and may be fitted with an artificial foot in about two months after operation.

Difficulties. These have been already indicated in describing the operation. The first difficulty is planning the incisions properly. If the foot be pointed and the fact pass unnoticed, both the dorsal and plantar incisions will be wrongly placed, the former being over the neck of the astragalus, whilst the latter will run too far forward and will make the heel flap so large that it cannot be retracted without great difficulty and much bruising. On no account should the incision on the inner side be carried behind the tip of the internal malleolus; if this be done, the trunk of the posterior tibial artery will almost certainly be wounded.

The only other difficulties occur during disarticulation and are both avoided by keeping the knife close to the bone; they are wounding the vessels in the inner side of the flap, and button-holing the skin at the back of the heel while the os calcis is being dissected out. During this part of the operation the foot should be kept pointing straight forward and not twisted from side to side as is commonly done; any lateral displacement is likely to end in button-holing the skin.

When the soft parts over the back of the heel are damaged, it will be impossible to do Syme's amputation, and some other form of disarticulation must be used. Disarticulation is always preferable to an amputation through the lower end of the leg if it can be done, as the ability to bear his full weight upon the stump is a matter of great consideration to the patient.

There are two useful alternative operations to Syme's amputation. They are disarticulation by a large internal flap, and that known as Roux's operation, which is by means of a postero-internal flap. The incisions for both these operations are really only modifications of those for the sub-astragaloid amputations, the first resembling Farabeuf's, the second the racket method.

Operation by a large internal flap. This is really an improvement by Farabeuf upon the internal flap method of Sédillot, and the incision is practically identical with that of Farabeuf's sub-astragaloid disarticulation, except that it is not carried so far forward. It is a useful and simple method and is not so tedious to perform as Syme's amputation, and in this respect is undoubtedly superior to it. It is, moreover, hardly at all inferior to Syme's in the capability of the stump to bear any ordinary amount of pressure. The flap is thick and well nourished and the tendo Achillis is adherent to it; it is easier to raise than the flap in Syme's amputation. It is described here as an alternative operation to Syme's as it is not likely to be suitable for cases in which it is essential to do the latter.

Operation. The position of the limb, &c., is the same as for the sub-astragaloid disarticulation (see p. 296). *On the left foot,* the incision is commenced over the tendon of the extensor hallucis longus, just behind the tubercle of the scaphoid, and is carried out over the dorsum for about two inches, when it curves back towards the external malleolus, immediately beneath which it passes horizontally back to the outer border of the tendo Achillis near its insertion into the os calcis. The knife is then entered again over the tendon of the extensor hallucis longus, and carried down across the inner border of the foot to the centre of the sole on a level with the articulation between the scaphoid and the internal cuneiform. Thence the incision curves backwards to the outer border of the foot, along which it is carried as far as the back of the heel, when it turns upwards to join the first incision (see Fig. 113).

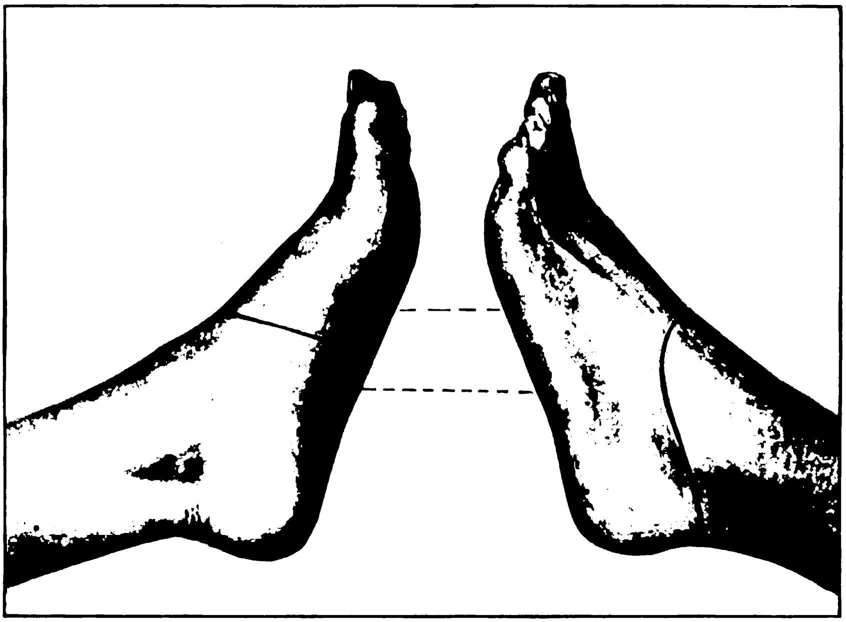

FIG. 113. DISARTICULATION AT THE ANKLE BY A POSTERO-INTERNAL FLAP.

The foot is now held in the same position as for the sub-astragaloid disarticulation (see p. 300). The parts in the dorsal incision are divided down to the bone, and the upper lip of the incision is raised until the external malleolus is seen and the ankle-joint is rendered accessible. The external lateral ligament is divided in front and behind it, while the foot is bent downwards so as to open up the joint freely; the tendo Achillis is also cut. The astragalus is forced well out of the tibio-fibular arch, and the internal lateral ligament is divided from the inner side. The final steps of the operation are identical with those of the sub-astragaloid amputation. After disarticulation the malleoli are cleared and sawn, as in Syme's amputation (see p. 310).

On the right side the incision commences at the outer border of the tendo Achillis, and runs parallel to the outer border of the foot and just beneath the tip of the external malleolus as far forward as the mid-point between the malleolus and the tip of the fifth metatarsal bone, when it curves inwards across the dorsum as far as the tendon of the extensor hallucis longus, about half an inch behind the tubercle of the scaphoid. The foot is then turned over to the left, and the incision is carried across the inner border of the foot with a slight convexity forwards on a level with the articulation between the scaphoid and the cuneiform bones. From this point it runs to the centre of the sole, and then curves back to the outer border, along which it runs as far as the external tuberosity of the os calcis, whence it is carried upwards to join the commencement of the first incision.

The Racket method (large postero-internal flap). This is the operation that is called by the name of Roux. The incision runs from the outer border of the tendo Achillis horizontally forwards about half an inch below the external malleolus until it reaches the mid-point between that structure and the base of the fifth metatarsal; then it curves forwards over the dorsum, crosses the inner side of the foot just in front of the tuberosity of the scaphoid, and thence runs transversely across the sole to the tuberosity of the fifth metatarsal. From this point it curves gradually backwards to join the commencement of the first incision. The incision goes down to bone throughout, and each edge of it is dissected up in turn as far back as possible; it is more difficult to raise the flaps sufficiently from the lateral surfaces of the os calcis in this operation than in the one just described. After the flaps have been raised as far as possible, the ankle-joint is opened from the front and outer side, and the removal of the foot is effected by a procedure similar to that just described (*vide supra*). The internal lateral ligament is divided from its inner aspect, and the edge of the knife is kept closely in contact with the bone while the latter is being dissected out of the flap.

A tourniquet round the middle of the thigh is used in Syme's and all similar operations.

TRANS-CALCANEAL AMPUTATIONS

Pirogoff's amputation. The only important objection to Syme's amputation is that it shortens the limb, and a number of operations have therefore been devised with the object of retaining some portion of the os calcis, which is subsequently united to the cut surfaces of the tibia and fibula, thereby reducing the shortening to a minimum; at the same time this allows the patient to bear his weight upon the part of the heel that is intended to support it in the natural state. In the pre-antiseptic days Pirogoff's operation was strongly recommended in preference to Syme's because of the risk of septic infection followed by sloughing of the flap that so often accompanied the latter. Such an accident was very serious owing to bruising of the flap while it was being raised, the narrowness of its base, its indifferent blood-supply, and the cavity left in the stump in which the discharges collected. These risks, however, have no weight at the present day, and as the shortening of the limb after Syme's amputation is of little consequence when compared

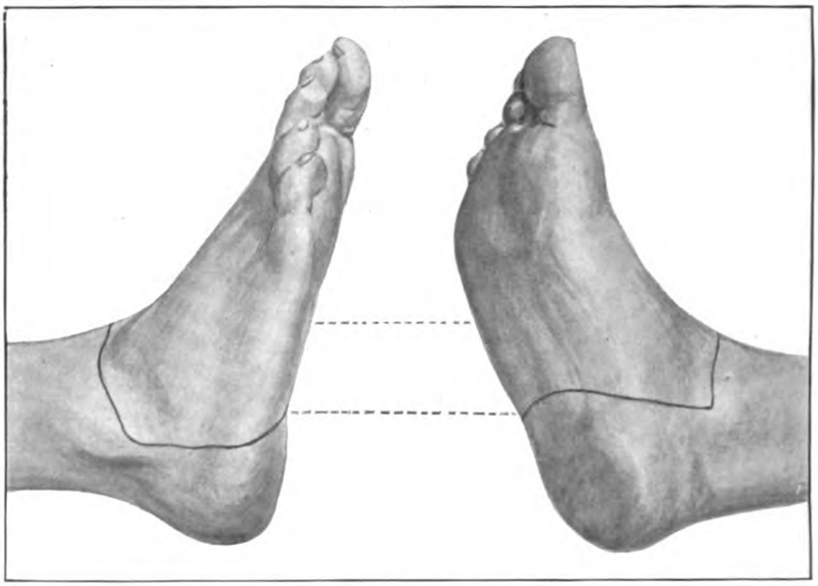

FIG. 114. INCISIONS FOR PIROGOFF'S AMPUTATION.

with the excellence of the stump it provides, and as experience shows that the functional results of Pirogoff's amputation are not nearly so uniformly good as those after Syme's, the former operation has fallen steadily into disuse, and it is now rather a dissecting-room exercise than an operation of actual practice. It requires an exceptionally neat piece of carpentry to cut the bone surfaces so as to make sure that the patient shall bear his weight upon the tuberosities of the os calcis when the cut surfaces are put in apposition, and, even if the section has been accurately made, it is not always possible to secure bony union; if this fails, severe neuralgia and a painful stump are likely to occur. Moreover, neither Pirogoff's amputation nor any of its modifications is suitable for cases of tuberculous disease, as recurrence would almost certainly take place.

Operation. The position of the limb is similar to that in Syme's amputation, and a tourniquet is applied to the thigh about its centre. The incisions also are similar, except that the one crossing the sole is directed forwards towards the toes instead of vertically down in the continuation of the long axis of the leg. The soft parts are incised down to the bone and the heel flap is dissected up for an inch and the skin allowed to retract. The joint is opened from the front by the incision across the dorsum (see Fig. 114), and the lateral ligaments are divided, the front of the foot being firmly depressed until the astragalus protrudes from beneath the tibio-fibular arch, and the upper surface of the os calcis behind it is brought into view.

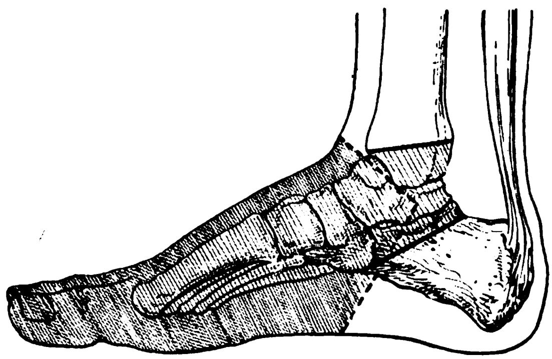

FIG. 115. LINES OF BONE SECTION IN PIROGOFF'S AMPUTATION. It will be seen that the two incisions through the bone are nearly parallel. The dotted lines represent the skin incision, and the shaded portion denotes the bones and soft parts that are removed in the amputation.

The saw is applied to the os calcis immediately behind the posterior articular surface, and the bone is divided from behind obliquely forwards and downwards along the line of the plantar incision through the soft parts. After the foot has been removed thus, the malleoli are cleared, and the lower end of the tibio-fibular arch is sawn through from the front obliquely upwards and backwards in a direction nearly parallel to the saw cut in the os calcis. Unless the two incisions are almost parallel the two bony surfaces will not fit accurately (see Fig. 115).

The cut surface of the os calcis is now applied to the cut surfaces of the tibia and fibula, and is kept in position either by a few stout sutures going through the periosteum of the two adjacent bony surfaces, or, if preferred, by mechanical means such as wires, pegs, tacks, or screws. No drainage tube is required, and the dressings are applied as in

Syme's amputation. The position of the posterior part of the os calcis in a properly performed amputation is shown in Fig. 116.

Other trans-calcaneal operations. Numerous modifications of this

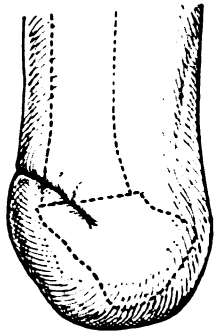

FIG. 116. THE STUMP AFTER PIROGOFF'S AMPUTATION. The dotted lines show the position of the bones after they are united. If this be compared with the preceding figure it will be seen that the patient walks nearly upon the same portion of the heel as before the operation.

operation have been devised with the object of replacing Pirogoff's oblique section through the os calcis by a horizontal or a vertical one. The latter is a very bad plan and needs no further description; after the

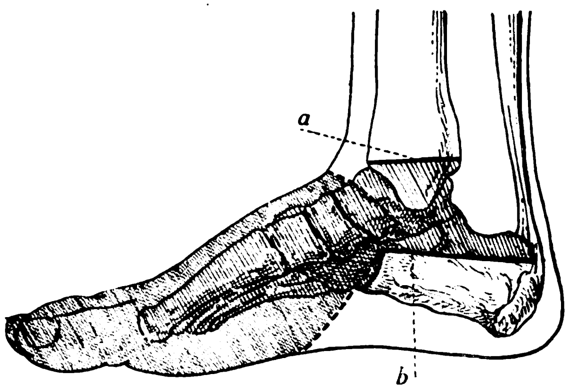

FIG. 117. LE FORT'S AMPUTATION. The thick dark lines *a* and *b* denote the lines of bone section; the shaded portions are the parts of the foot removed in the amputation.

operation the patient would walk on the posterior surface of the os calcis, which is not calculated to bear weight and is likely to give rise to trouble.

Le Fort's operation. The best known trans-calcaneal amputation with horizontal division of the os calcis is the one that goes by the name of Le Fort; the line of bone section runs horizontally below the sustentaculum tali (see Fig. 117). Although theoretically this is a good operation, inasmuch as it does not oblige the surgeon to make an oblique bone section through both os calcis and tibia and fibula, and inasmuch also as it gives a wide bone surface for union, yet it is difficult to perform, and offers no points of importance justifying its description here.

Gordon Watson's modification. Mr. C. Gordon Watson showed at the Clinical Society on April 24, 1907, two cases on which he had performed a trans-calcaneal amputation of the foot, which is a considerable improvement upon Pirogoff's amputation and an advance upon that

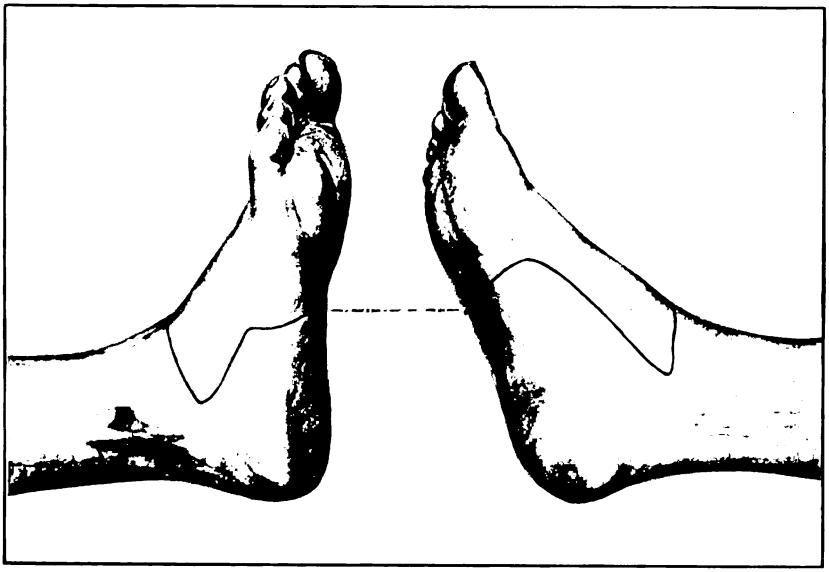

FIG. 118. INCISIONS FOR GORDON WATSON'S AMPUTATION.

practised by Le Fort. It provides the patient with a sound stump capable of bearing his full weight, while the shortening of the limb is reduced to a minimum. Moreover, the weight of the limb is borne upon the heel in its normal position—a result that cannot always be obtained in Pirogoff's amputation. Le Fort's operation aims at the same results, but it is easier to obtain them by Mr. Gordon Watson's amputation, and in the latter operation there is also less bone removed than in Le Fort's.

The operation is done as follows:—A dorsal flap, extending from a point half an inch below and behind the tip of the internal malleolus to the tip of the external malleolus, is made by a bold downward sweep an inch and a half below the line joining the tips of the two malleoli across the dorsum (see Fig. 118). The plantar flap is marked out by an incision through the skin only, extending from one extremity of the dorsal flap downwards and forwards to half an inch in front of the prominence of the scaphoid on the inner side, or half an inch in front of the base of the fifth metatarsal on the outer side, and transversely across the sole of the foot between these two points.

The dorsal flap is dissected up, the soft parts are divided, and the ankle-joint is opened from the front as in doing Pirogoff's amputation. The foot is now firmly depressed, and the attachments of the internal lateral ligament to the astragalus are divided with the point of the knife, and the anterior fasciculi of the external ligament are similarly

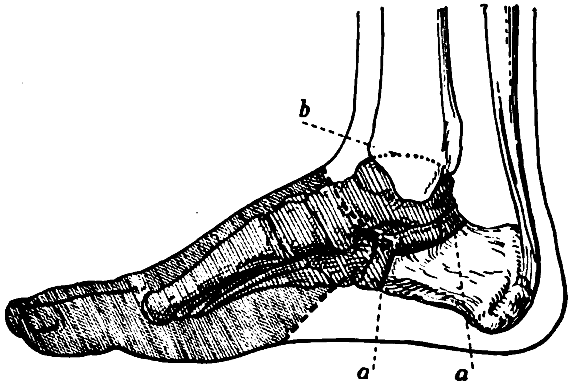

FIG. 119. GORDON WATSON'S TRANS-CALCANEAL AMPUTATION. The thick black line *a-a* is the section of the os calcis corresponding roughly to the articular surfaces. The dotted line *b* is intended to denote the level at which the articular cartilage is removed from the under surface of the tibio-fibular arch. The shaded portions are the parts removed.

treated. The foot is next inverted forcibly and the point of the knife is passed between the os calcis and the astragalus, and divides the interosseous ligament and also opens the astragalo-scaphoid joint, and frees the head of the astragalus from the scaphoid. This enables the astragalus to be seized in lion forceps and twisted so as to put on the stretch the posterior fasciculus of the external lateral ligament and the posterior ligament, both of which are divided; the astragalus is then removed.

The only thing that now prevents the os calcis from being brought up into contact with the under surface of the tibia is the projecting sustentaculum tali, which comes into contact with the internal malleolus. The former structure is cut away freely with a chisel or gouge until the upper surface of the os calcis lies close against the under surface of the tibio-fibular arch, and the next step is to clear the articular surfaces of the os calcis, tibia, and fibula of cartilage with a gouge or chisel. The surfaces are so fashioned that the bony surfaces fit accurately when the foot is at right angles to the leg (see Fig. 119).

Up to this point the connexions of the front of the foot with the os calcis have been left undisturbed, so as to facilitate manipulation, but the operation is now completed by opening the calcaneo-cuboid articulation and separating the foot by cutting obliquely through the soft tissues of the sole from above downwards to the margin of the plantar flap already marked out. Usually about half an inch of the anterior and of the os calcis is removed with a chisel, and this bone is brought up into apposition with the raw surfaces of the tibia and fibula, and fixed there by some suitable means, such as a long pin traversing the whole thickness of the os calcis and left projecting through the skin, to be removed when union has taken place. Any other means of fixation may of course be made use of.

In Mr. Gordon Watson's cases the amputation was done for severe long-standing talipes equinus due to infantile paralysis, and consequently it was impossible to bring the os calcis into position at right angles to the leg without dividing the tendo Achillis and the contracted tissues around it. When the flaps are brought together, the long plantar flap folds up over the anterior end of the os calcis, and the cicatrix is drawn up slightly upon the dorsal surface where it is out of reach of pressure.

The flaps are sutured in the ordinary way, and it is a good plan to put the limb up in plaster for a fortnight, when the stitches and the pins, if they are projecting as described above, may be removed. The plaster is then re-applied and kept on until firm bony union has occurred, the patient meanwhile walking upon the bent knee on a peg-leg. Neither of Mr. Gordon Watson's patients was allowed to put the foot to the ground for three months, but so long a period of rest will probably not be necessary when the nutrition of the parts is good.

The resulting stumps were excellent in all respects; the patients could walk, run, and jump upon them without the least inconvenience. The operation certainly deserves an extended trial.

CHAPTER VII

AMPUTATIONS OF THE LEG AND KNEE

AMPUTATIONS THROUGH THE LEG

WHEREAS formerly it was the custom not to amputate between the lower end of the tibia and 'the seat of election'—viz. a hand's breadth below the top of the tibia—it is now the custom to apply to the leg the same rule as to the arm, and to amputate as low down the limb as the condition of the parts permit. There are many reasons why this should be so. The lower the amputation is practised, the less are the risks, immediate and remote, that the patient runs, and the longer the leverage below the knee the more useful is the artificial limb; provided therefore that the latter can be fitted so as to cause neither pressure upon the end of the stump nor undue friction upon its anterior surface, the surgeon should amputate as low down the limb as possible.

There are cases, however, in which it is still preferable to amputate at 'the seat of election'. As its name implies, this is the spot at which the surgeon, with the whole length of the limb at his disposal for an amputation, elected to do the operation, and his preference for this particular spot was largely due to the manufacture of artificial limbs being so unsatisfactory that the patient always had to bear his weight upon the bent knee; it was therefore an advantage that the portion of the limb remaining below the knee-joint should be as short as possible, so as to prevent an unsightly projection from the artificial limb. Another reason for choosing this spot was that the blood-supply to the flaps was ample, and therefore there was less chance of sloughing if sepsis supervened. At the present day it is better to amputate at 'the seat of election' for labouring men and all those who have to follow laborious occupations and are unable to afford a well-fitting artificial limb. In such cases a peg-leg allows them to follow their employment, and the stump is little likely to be exposed to injury even under the most adverse conditions.

The performance of an amputation through the leg is accompanied by certain difficulties, largely attributable to the anatomical conformation of the parts. The flaps must be planned so that the cicatrix does not fall over the end of the bones, for, although the pressure is only rarely borne directly upon the end of the stump in the artificial limb, yet the bone has a constant tendency to be pressed down against the end of the stump, and a painful and adherent cicatrix is likely to occur should the latter be terminal. Again, the sharp subcutaneous border of the tibia may give rise to irritation from pressure against the artificial limb, and must therefore always be bevelled off so as to avoid this. The tapering contour of the limb makes it important to exercise much care in cutting the flaps, as a conical stump due to short flaps is a dire misfortune in the lower extremity. Rectangular flaps, therefore, which measure half the circumference of the limb across their base ought, if properly cut, to measure more than half the circumference of the limb across their extremity, a point often forgotten when operating upon the dead subject, with the result that tapering and ill-fitting flaps are constantly produced. The flaps are somewhat difficult to raise when it is desired to take up the muscles with them, as the anterior muscles of the leg are wedged in deeply between the tibia and the fibula and cannot be cut by transfixion; moreover, the anterior tibial artery, which supplies the anterior flap, lies deeply down on the interosseous membrane, and is easily wounded when the anterior flap is being raised. The posterior muscles, however, can be cut by transfixion, and, since they retract much more freely than those on the anterior surface, they should be cut as low down as possible, in order that the amount of retraction on the two sides shall be equal. Owing to the greater power of the posterior muscles they always pull the posterior flap backwards, at any rate when the amputation is below the centre of the leg. Therefore the cicatrix must lie well up on the front of the leg if the amputation has been done by a long posterior flap; when possible, however, it is well to cover the end of the stump with a flap derived from the surface that is most calculated to bear pressure.

In an amputation through the leg below 'the seat of election' the weight is borne by the expanded upper end of the tibia, which fits into a conical socket accurately moulded to it. Weight-bearing stumps are possible here also and there can be no objection to attempting to secure them. If such a stump can be secured, the patient is much more comfortable and the gait more nearly normal. This is naturally more difficult in the lower part of the leg. The increased leverage obtained with a long stump must be weighed against the greater probability of securing a weight-bearing stump by amputation through the middle third. Those who do not attempt to secure the weight-bearing stump by most careful and systematic after-treatment, should amputate as low down as possible. Instrument makers still object somewhat to a long stump on the ground that its end is apt to get fretted against the front of the apparatus in flexion and extension of the limb; this, however, is entirely a matter of proper fitting and should not weigh against the great advantage given to the patient by the increased leverage and usefulness of the limb. More attention should be devoted to the choice of the amputation in the lower extremity than has hitherto been the case, as patients begin to realize that inability to walk comfortably afterwards is largely due to a defect in the operation.

Out of the numerous amputations that have been introduced the following have been selected as being most applicable to the various conditions likely to be met with in practice. They may be divided into three large groups, namely:—

(i) *Supra-malleolar amputations,* or all the amputations between the level of Syme's amputation and the junction of the lower with the middle third of the leg.

(ii) *Amputations in the middle of the leg.*

(iii) *Amputation at 'the seat of election'*—i.e. a hand's breadth below the top of the tibia.

In all these amputations the circulation is best controlled by the application of Esmarch's rubber tubing horizontally around the middle of the thigh.

Indications. (i) *The supra-malleolar amputations* are suitable for cases of injury in which the foot is extensively destroyed, but the tissues over the region of the heel are sound. In these cases, however, it is likely that the surgeon will often be able to perform a Syme's amputation, which of course is better, inasmuch as it gives a longer stump and one better able to stand pressure.

The supra-malleolar amputation, however, possesses advantages over Syme's when the amputation is performed for tuberculous or other disease of the ankle-joint. The serious objection to Syme's amputation for these conditions is that in it it is difficult to be sure that the incisions have been carried beyond the limits of the disease, owing to the conformation of the joint and the presence of the tendon sheaths in close connexion with it. By a supra-malleolar amputation, however, the whole of the synovial membrane is removed along with the foot, and any diseased tendons or tendon sheaths are probably removed also owing to the higher division of the soft parts; in any case they can be dissected out with rapidity and certainty at the end of the operation.

(ii) *Amputations through the middle of the leg* will usually be done only for injury, and are chiefly used for compound fractures of the lower third of both bones. This amputation is too high up for tuberculous disease, and too low down for a growth of the bones; it is perhaps the most difficult form of amputation of the leg to perform satisfactorily.

(iii) *Amputation at 'the seat of election'* is most suited for the working man who does not desire an artificial limb and wishes to engage in heavy labour with the least inconvenience. It is also used for compound fractures high up the limb, for extensive chronic ulcers which have resisted treatment, and for certain cases of long-standing infantile paralysis, accompanied by wasting of the entire limb, in which the nutrition of the parts is so feeble that an amputation lower down would be precarious. It may be done occasionally for gangrene of the toes when the local blood-supply is good enough to justify the surgeon in trying to save some part of the leg; it will rarely be employed for this affection, however, as the collateral circulation is seldom good enough.

SUPRA-MALLEOLAR AMPUTATION

By the oblique elliptical incision. This amputation is attributed by Farabeuf to Guyon, and really differs but slightly from Syme's amputation. The incision and the subsequent steps of the operation are very similar, the lower ends of the tibia and fibula being sawn an inch

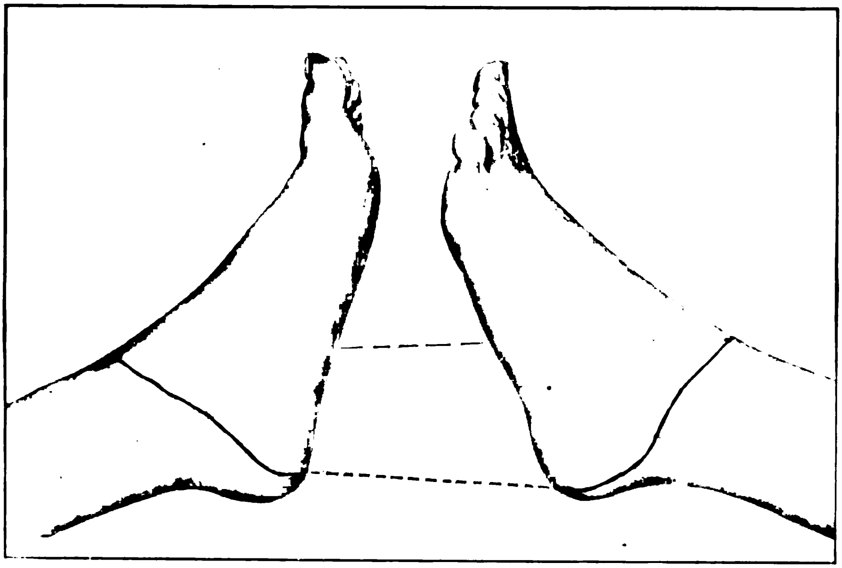

FIG. 120. SUPRA-MALLEOLAR AMPUTATION BY THE OBLIQUE INCISION.

or more higher than in Syme's amputation. I have used the operation several times and can speak very highly of the excellence of the stump; the expanded end of the ends of the tibia and fibula furnish a firm base upon which the weight can be safely borne. The medullary canal is not opened unless the bone section be made considerably above the malleoli.

The stump is covered by a flap taken from the posterior surface of the heel, which is well calculated to bear pressure.

Operation. The surgeon faces the sole of the foot, which should project well beyond the end of the table. He seizes the front part of the foot in his left hand and turns it over to his right so as to commence the incision (see Fig. 120) at the convexity of the heel; this will therefore be begun on the outer side in the right foot, and on the inner in the left. From the point of the heel it is carried somewhat forwards and upwards until it is almost vertically below the tip of the internal malleolus on the left side, or the corresponding point half an inch in front of the outer malleolus on the right side. Thence it runs almost vertically up to the malleolus and then sweeps upwards and forwards across the front of the ankle-joint. The front of the foot is now turned over to the left, and a corresponding incision is traced on the opposite

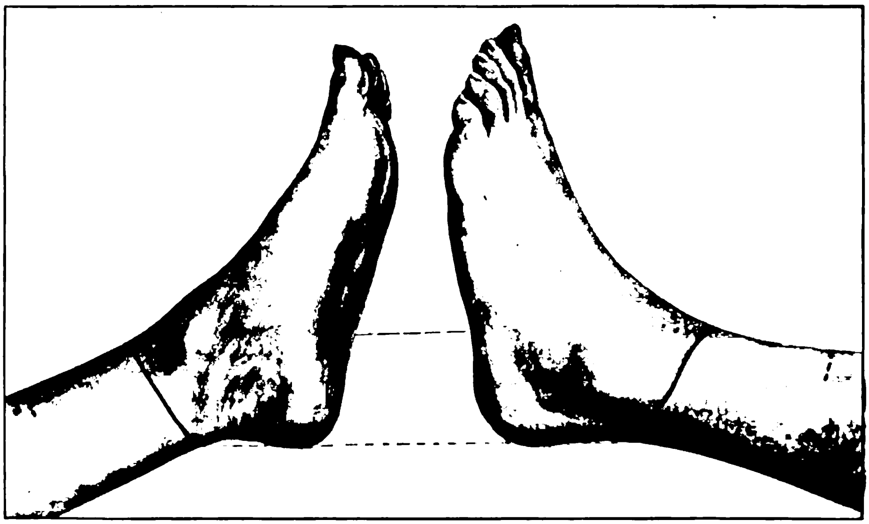

FIG. 121. MARCELLIN DUVAL'S AMPUTATION THROUGH THE LOWER THIRD OF THE LEG BY THE OBLIQUE INCISION. The dotted lines indicate the level upon which the bone is sawn.

side of the foot until it meets the commencement of the previous one over the point of the heel. This gives an elliptical incision, the lateral appearance of which is somewhat like an italic letter *J*.

This incision goes through the skin only, which is allowed to retract, and the knife is then carried down to the bone all round on the level with the retracted skin. Instead of dissecting up the heel flap it is easier to open the ankle-joint and disarticulate from the front, as in Syme's amputation, and then to dissect out the os calcis from the flap (see p.

309). When this has been done, the lower ends of the tibia and fibula are cleared by dissecting up the soft parts for about two inches, making four subcutaneous incisions, one over each of the anterior and posterior surfaces of the lower ends of the tibia and fibula, so as to raise the tendons and soft parts *en masse* from the bones, which are then cleaned and sawn transversely an inch or so above the level of the articulation. As a rule the bone section will be just where the bones are expanding to form the joint surfaces. The cicatrix will lie on the front of the limb above the line of the bone section. The after-treatment is the same as for Syme's amputation.

Another amputation by an oblique elliptical incision is that sometimes called by the name of Marcellin Duval, which is suitable for amputations rather higher up the limb than the one just mentioned. It is not such a good one as either this or the succeeding operation, as it gives a somewhat puckered cicatrix lying very near to the end of the bone; it is inapplicable to cases in which there is inflammatory matting of the soft parts.

The point of bone section is first fixed upon, and an oblique elliptical incision is traced out, the lowest level of which is at a distance below this point equal at least to the antero-posterior diameter of the limb at the level of bone section, and the upper limit of which is equal to half that distance below it. Looked at laterally, the line of incision crosses the vertical axis of the leg at an angle of about 45° (see Fig. 121). In estimating the distance which the incision should extend below the point of bone section, allowance has to be made for the retraction of the cut skin; therefore a full third must be added to allow for the shrinkage of the skin flap. The surgeon stands on the patient's right of the limb to be removed, viz. on the outer side of the right limb and on the inner side of the left. The leg is drawn well over the end of the table and is held horizontal by an assistant, who manipulates it as may be necessary during the course of the operation. The surgeon first marks out that portion of the incision which is on the side of the limb nearest to him, the foot being rotated away from him. He begins the incision from above downwards: when he has cut it on the side nearest him he bends over the limb (the foot being rotated towards him) and finishes the incision on the opposite side from below upwards.

After the skin has been allowed to retract, the cuff of skin is pulled well up and freed from the subcutaneous tissues by a few touches of the knife, the soft parts are divided right down to the bone close to the margin of the retracted skin, and the muscles are dissected up for a good half-inch or so beyond the proposed point of bone section. The bones are then divided and the projecting triangular subcutaneous edge of the tibia is removed (see Fig. 122), so as to avoid pressure against the flap. Any tendons are cut short, and an inch of the posterior tibial nerve is dissected out and removed. In bringing the flaps together one or two of the deep tension sutures are made to penetrate the tendo Achillis, which is thereby assured of a firm hold upon the flap. A drainage tube should be put in the outer angle of the wound. The after-treatment is similar to that of Syme's amputation.

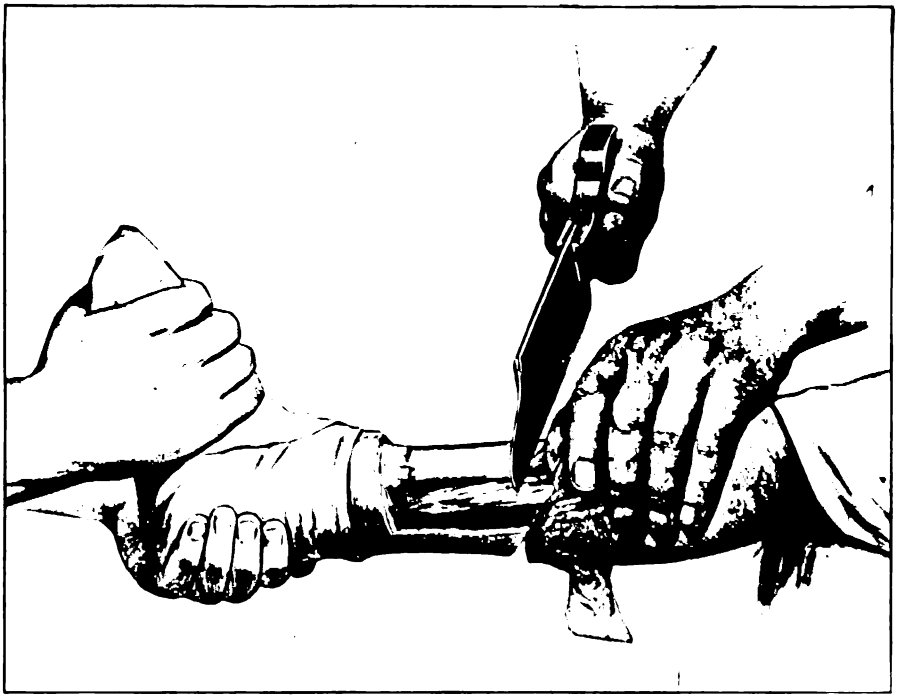

FIG. 122. METHOD OF BEVELLING OFF THE SUBCUTANEOUS EDGE OF THE TIBIA. The oblique cut has been made, and the saw is dividing the bone transversely below it. As the latter crosses the oblique cut the small triangular portion is removed, and when the bone is severed it leaves the sharp subcutaneous margin of the tibia bevelled off.

By a long posterior flap. This method presents advantages when the amputation has to be done rather higher up than in the previous cases, as the tapering contour of the limb renders it difficult to get proper coaptation with an oblique elliptical incision. Moreover, when the amputation is done for inflammatory conditions the method of raising the flaps is superior to the sliding method employed in the elliptical incision.

There are many modifications of this operation, but the difference between them consists mainly of variations in the lengths of the anterior and posterior flaps respectively. If possible, an amputation by antero-posterior flaps should have the posterior flap longer than the anterior, as the skin of the front of the leg is not so well calculated to bear pressure. The best form of amputation by unequal flaps, therefore, is that by a long posterior and short anterior.

Operation. The limb is brought well over the end of the table and the surgeon stands facing the foot. The left thumb and forefinger are placed respectively upon the centre of each lateral aspect of the limb opposite the point of bone section, and the incision begins just below this on the right side of the limb as the surgeon faces it. The knife is carried down the lateral aspect of the limb, on the one side just in front of the inner border of the tibia, and on the other immediately behind the fibula, for a distance corresponding to rather more than the antero-posterior diameter of the limb at the point of bone section. The incision must not be carried down the mid-line of the lateral aspect of the limb, as otherwise, owing to the tapering shape of the leg, the flap will be pointed instead of being rectangular; it must incline a little forwards. At the lower end of this incision the knife is carried transversely across the back of the limb for a distance equal to half the circumference of the limb at the point of bone section, and then vertically up on the opposite side of the limb to the point opposite that from which it started; the corners of the flap should be slightly rounded. It will be noticed

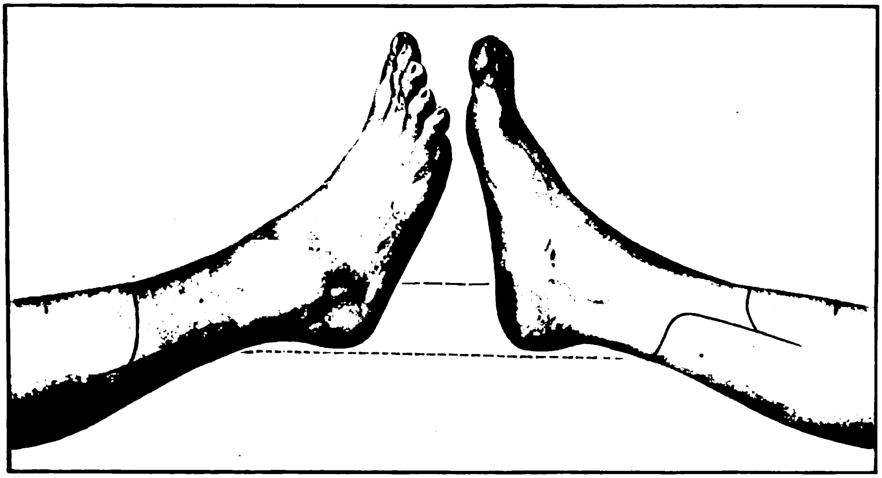

FIG. 123. AMPUTATION THROUGH THE LOWER THIRD OF THE LEG BY A LONG POSTERIOR FLAP. The level of the bone section is shown by the dotted line above.

that in cutting the flap in this operation the operator has to change his position; he first stands facing the sole, but, as the incision for the posterior flap is traced out, he moves round until eventually he is on the side at which the incision ends; that is to say, he will eventually be on the patient's right of the limb operated upon. A large U-shaped flap is thus marked out on the back of the leg, and the incision is deepened all round so as to allow the skin to retract fully. The anterior incision is then marked out by drawing the knife transversely across the limb about two inches below the point of bone section (see Fig. 123).

The first step in raising the large posterior flap is to open the deep

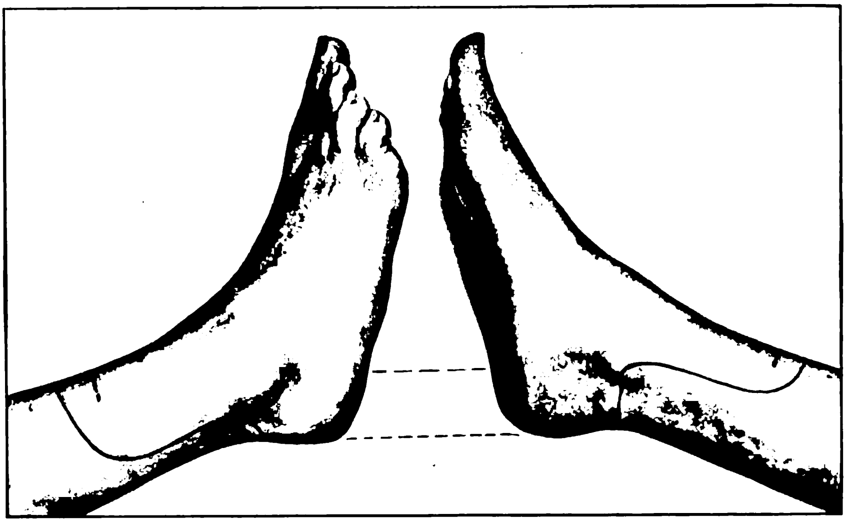

FIG. 124. AMPUTATION THROUGH THE LOWER THIRD OF THE LEG BY A SINGLE POSTERIOR FLAP. The level of the bone section is shown by the dotted line. In this case the cicatrix is placed so high up on the front of the bone that there is no risk of the pull of the calf muscles bringing it over the end of that structure.

fascia throughout the posterior incision, and to insert the thumb and forefinger between the tendo Achillis and the bones, so that the former structure can be pulled well away from them and divided from within outwards; the other muscles at the back of the leg are then treated similarly. The peronei muscles, however, should be divided down to the fibula close to the junction of the flaps. The anterior flap is then raised by dividing the deep fascia and the muscles down to the interosseous membrane on a level with the margin of the retracted skin, and raising all the muscles and the anterior tibial artery from the interosseous membrane and the bones. The flaps are well retracted, the interosseous membrane is divided and the bone sawn, the anterior margin of the tibia being bevelled off in the usual manner (see Fig. 122). The posterior tibial nerve must be isolated and dissected out from the whole length of the flap, otherwise it will give rise to pain subsequently.

This operation has been modified by cutting the posterior flap still longer and providing no anterior flap at all (see Fig. 124). This method, by placing the scar well up on the front of the bone, guards against its being exposed to undue pressure, and may be called for when the tissues at the disposal of the operator are scanty in front; but otherwise the preceding method is preferable. Various other methods, such as a circular amputation or equal lateral flaps, have been practised, but should be avoided, as the cicatrix resulting therefrom falls directly over the end of the bones and a certain amount of pressure upon the scar is unavoidable. It is better to amputate higher up than to fashion a stump by these methods.

AMPUTATION THROUGH THE MIDDLE OF THE LEG

Amputations in this situation fell into disuse for a long time in favour of those at 'the seat of election', for the reasons already given (see p. 320). They are now becoming more popular, however, and should certainly be practised if occasion offers. In this situation, as in the supra-malleolar region, the flaps must be fashioned so that the cicatrix is not terminal, and therefore they must be unequal, the operation of choice being one with a long posterior and short anterior flap. The flaps should not consist merely of skin and the superficial structures, but should take up the muscles down to the bone together with the main vessels.

The operation that perhaps will be found best on the whole is that known as Hey's, consisting of a long posterior and a short anterior flap. The method of Teale, in which there is only a long anterior rectangular flap measuring half the circumference of the limb in length, is not to be recommended, as the extreme length of the flap entails division of the bone so high up that one of the methods previously recommended may well be applied, and the bone divided at a lower level. It will happen occasionally, however, that the covering for the stump must be obtained from the anterior surface of the limb, and in that case Lord Lister's modification of Teale's amputation gives a good result.

Amputation by a long posterior and short anterior flap (Hey's amputation). The limb is drawn over the end of the table as far as the knee, and the surgeon stands on the patient's right of the limb to be operated upon; the opposite limb is flexed at the knee and fastened down to the table. The point of bone section is fixed upon and the antero-posterior diameter of the limb at that spot estimated, the incision beginning a good finger's breadth below this. The posterior flap should be equal in length to this measurement, while the anterior will be one-third the length of the posterior. Both must be rectangular, and the transverse measurement at their lower extremities must be equal to that at their base. The flap is best cut by carrying down an incision on each side from a point a finger's breadth below the line of bone section and joining these by a transverse cut behind the limb, slightly rounding the corners in doing so. The anterior flap is marked out by

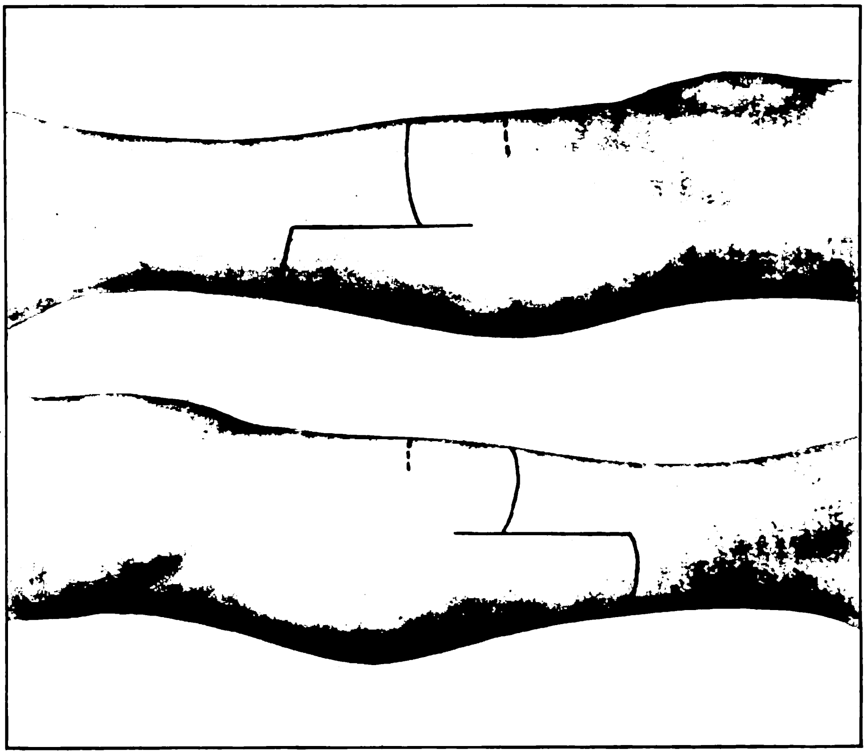

FIG. 125. HEY'S AMPUTATION THROUGH THE MIDDLE OF THE LEG. The dotted line indicates the level at which the bones are sawn.

drawing the knife across the front of the limb a third of the way down, slightly rounding the corners also (see Fig. 125).

The incision is carried through the deep fascia so as to allow the skin to retract freely, and the posterior flap is dissected up for about an inch and a half, taking skin and deep fascia only, before the muscles are divided. The easiest way to divide the muscles is to flex the knee almost to a right angle and rotate the limb away from the operator, so that it lies upon its side, and then to insert the thumb and forefinger between the gastrocnemius and the bone, pull the muscle away, and divide it by oblique cuts from within outwards level with the margin of the retracted skin. Vertical incisions are then made through the deep fascia along the borders of the tibia and fibula, and the deep muscles on the back of the leg and the posterior tibial vessels are raised and pulled away from the bone with the fingers and the thumb, and cut at the same level from within outwards. All the soft parts are then raised to the level at which the bone is to be sawn, by means of the fingers and the handle of the knife. While this is being done, the foot should be raised so that the limb is nearly vertical. In the anterior flap the muscles and the anterior tibial artery are raised from the interosseous membrane and the bones by means of the fingers and handle of the knife, and are divided from within outwards and raised in one mass up to the level of

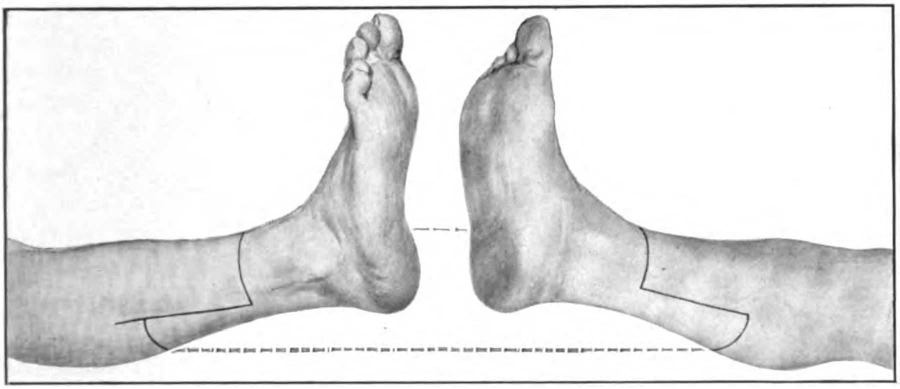

FIG. 126. INCISIONS FOR LISTER'S AMPUTATION IN THE MIDDLE OF THE LEG.

the bone section. The bones are then sawn, beginning and finishing as usual upon the tibia, the sharp anterior margin of which is bevelled in the usual manner (see Fig. 122).

The other operation by means of a large posterior flap in common use is that which goes by the name of Lee's operation, and which corresponds almost exactly to Teale's amputation, except that the long flap is on the posterior and not on the anterior aspect of the limb. The same objection applies to it as to Teale's amputation, viz. that it is unduly extensive, and that the adoption of some other amputation would enable the patient to preserve a longer stump.

Amputation by a single long anterior flap (Lister's operation). In order to overcome the objections to Teale's amputation, referred to above, Lord Lister devised the following operation (see Fig. 126), which I have used on many occasions, and which provides a very useful stump. His description of the operation is as follows (Holmes's *System of Surgery*, vol. iii. p. 717): 'Immediately above the ankle the operation is performed as follows. The diameter of the limb having been ascertained by spanning it, a straight longitudinal incision of that length is made on the inner side of the leg, and on the outer aspect another similar incision directly over the fibula and extending about an

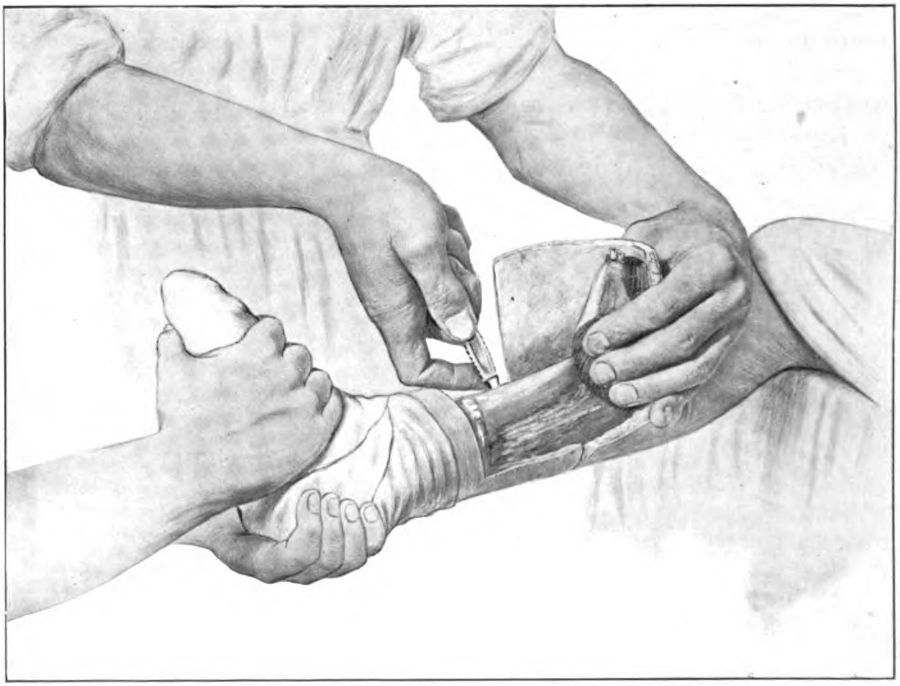

FIG. 127. LISTER'S AMPUTATION. CUTTING THE POSTERIOR FLAP. The figure shows the anterior flap raised with all the structures between the tibia and fibula right down to the interosseous membrane.

inch higher up. The lower ends of these incisions are connected by cutting across the front of the limb in a direction transverse in the main, but rounded off where it joins the lateral lines. The knife is then carried round the back of the limb to the bones, from the upper end of the internal incision to a point exactly opposite on the outer side, which will be about an inch below the upper end of the outer incision; the instrument being carried in a line slightly convex downwards, so as to form a very short posterior flap. The anterior flap is then raised in the manner above mentioned, including everything in front of the bones and interosseous membrane, after which the tibia and fibula are cleared as high as the level of the upper end of the outer incision, the finger-tip being still used in detaching the parts anterior to the interosseous membrane (see Fig. 127).

'In amputating through the calf on the same principle, the operation is similar, except that the anterior flap need not be longer than two-thirds of the diameter of the limb; but, to compensate for its diminution, the posterior flap must be made at least half as long as the anterior, by carrying the knife round the back of the limb at an angle of forty-five degrees through the integuments, and dissecting them up to the level of the upper end of the inner part of the incision, before cutting towards the bones, so as to get rid of the heavy and contractile mass of the sural muscles.'

This amputation gives a good firm stump, although the flap is somewhat ungainly and difficult to suture. It is admirably adapted to bear pressure, and the cicatrix is pulled well up out of the way by the calf muscles, so that there is no fear of its adhesion to the ends of the bones. The drainage tube is inserted at the upper end of the outer incision. The outer incision is made to extend higher up than the inner in order to get over the difficulty of retracting the muscles from the fibula owing to their intimate attachment to it.

AMPUTATION AT 'THE SEAT OF ELECTION'

The explanation of this term has already been given (see p. 320). In these amputations 'the seat of election' refers to the line of bone section, which is a full hand's breadth below the top of the tibia; in other words, nearly an inch below the tubercle of the tibia. This leaves a short portion of the leg below the knee-joint which can be moved freely, as the insertions of the quadriceps in front and the hamstrings and the popliteus behind are retained. Though flexion and extension of the joint are thus preserved, the stump is not long enough to cause any marked projection behind when the knee is flexed and the patient walks upon a peg-leg. It is perhaps the most useful stump for patients of the working class. Amputation in this situation has the further merit that it is not essential for the cicatrix to fall in any particular spot; indeed, in one of the favourite methods, namely, that by equal lateral flaps, it is directly terminal, a matter of little or no importance if the patient bears his weight upon the bent knee. This amputation can thus be performed in cases in which the soft parts are damaged quite close up to the level of the proposed bone section. It possesses the further great advantage, that almost any method of amputation may be employed; thus, equal or unequal antero-posterior or lateral flaps may be employed, or the circular method may be used, or a single flap may be fashioned either from the external or from the posterior surface. The three most generally useful methods are perhaps the circular method, that by equal lateral flaps, and that by the large external flap known by the name of Farabeuf.

The circular amputation. A tourniquet is applied round the middle of the thigh, the lower half of the thigh is made to project over

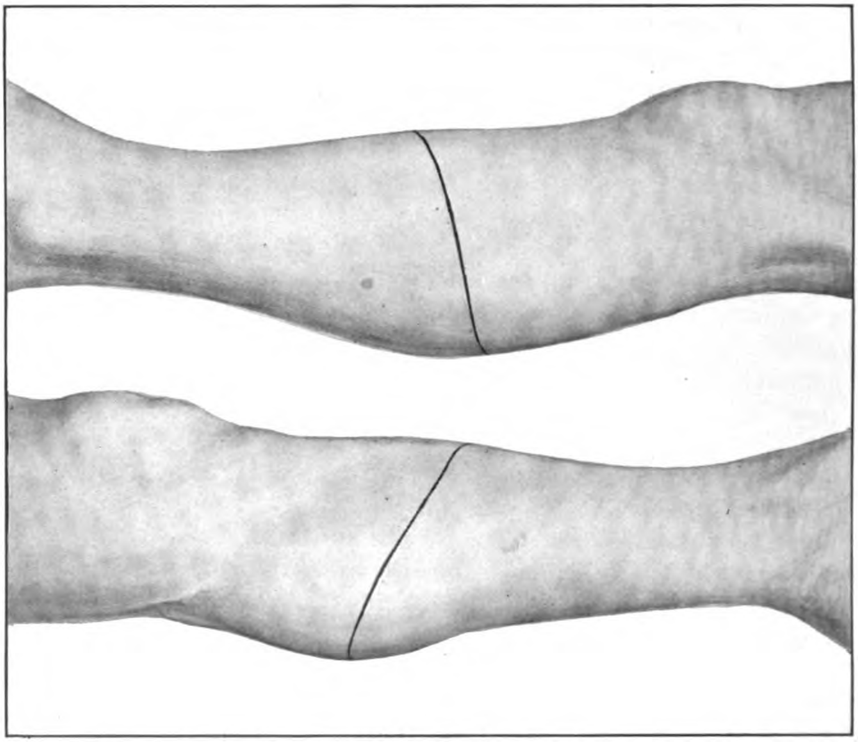

FIG. 128. AMPUTATION AT THE 'SEAT OF ELECTION' BY THE CIRCULAR INCISION. As will be seen, this incision is circular only in name; it is really an oblique one, extending lower down the limb in front in order to facilitate raising the flaps.

the end of the table, the other leg is fastened down out of the way, and the surgeon stands on the patient's right of the limb to be operated upon; an assistant holds the limb horizontal. The amputating knife should be nearly half as long again as the transverse diameter of the limb. The surgeon places his left thumb upon the point at which he is going to saw the bone, and divides the skin by a circular sweep of his knife at a distance below this point rather more than half the diameter of the limb at the level of bone section, so as to allow for the retraction of the soft parts (see Fig. 128). The arm is passed beneath the limb as in the ordinary circular amputation, and the knife is drawn round the limb with a slight sawing movement, passing lower down across the front of the leg than across the calf so that the incision is really an oblique one and not truly circular. If the incision cannot be completed in one sweep, it may be

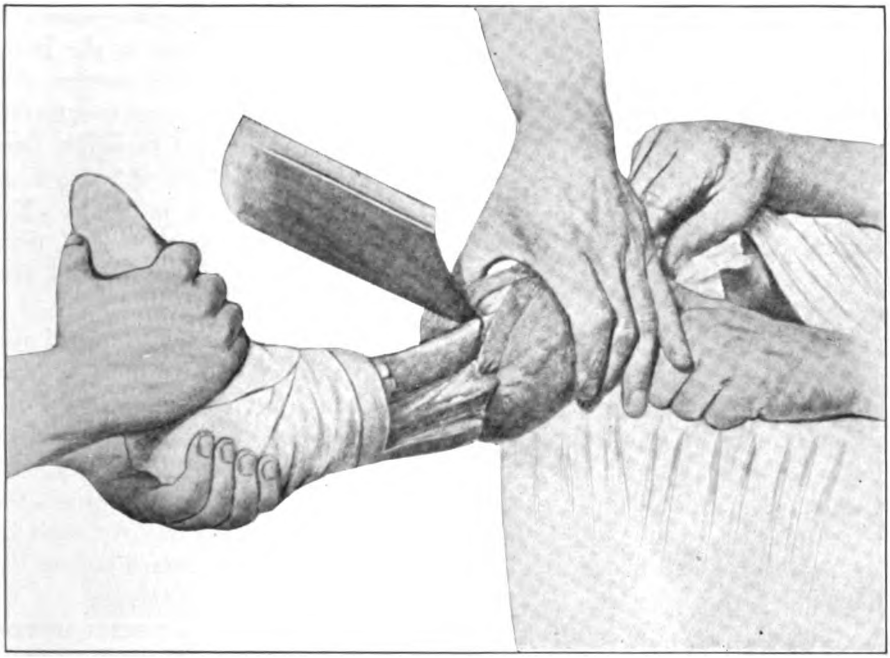

FIG. 129. THE THREE-TAILED LINEN RETRACTOR IN USE FOR AMPUTATION THROUGH THE LEG. The middle limb of the bandage goes through the interosseous space and passes under the two outer limbs which retract the soft parts from the tibia and fibula respectively.

finished by making the knife traverse in the opposite direction from the commencement of the incision to its termination. The knife is again passed lightly around the limb so as to divide any bands of cellular tissue that might interfere with due retraction of the skin, and the skin flap is dissected up for about two inches. The connexion between the skin and the front of the tibia is more intimate than elsewhere, and it will require repeated touches with the point of the knife to separate the flap here.

The limb is now flexed slightly and the gastrocnemius is pinched up between the thumb and forefinger, pulled away from the deeper structures, and divided on a level with the retracted skin without injuring the main vessels. The limb is then extended, and the soft parts, including the divided gastrocnemius but not the deep muscles on either the front or the back of the leg, are raised to about an inch below the proposed line of bone section. At this point an incision is made along the outer side of the crest of the tibia, and the fingers are sunk in between the bone and the tibialis anticus down to the interosseous membrane; the muscles and vessels are then divided transversely. The muscles on the posterior aspect of the limb are divided similarly, and the soft parts, back and front, are then raised from the interosseous membrane up to the point at which the bone is to be sawn. It is well to take the periosteum also for the last inch in cases of injury. Finally the interosseous membrane is divided, the soft parts are retracted by a three-tailed bandage (see Fig. 129), and the bones are sawn at 'the seat of election', the tibia being bevelled obliquely in front in the usual way (see p. 206). The section of the fibula should be completed first, and it is well, if time allows, to bevel off this bone obliquely from without downwards and inwards with a saw or a broad chisel.

The anterior and posterior tibial arteries, as well as the peroneal and some of the sural branches, will require ligature. There may be free bleeding from the nutrient artery to the bone, but this generally stops spontaneously; if not, the passage of a probe into the canal in which it lies will generally suffice to arrest it. Should this fail, Horsley's wax (see p. 591) should be pressed firmly into the orifice from which the bleeding comes, and will certainly succeed in stopping it. An inch of the posterior tibial nerve should be dissected out and removed before the flaps are sutured.

The flaps are approximated laterally so that the scar becomes antero-posterior. A drainage tube is inserted in the lower angle of the wound and removed in two days. The limb should be put upon a straight back splint with pads beneath the popliteal space so as to allow a little flexion, which greatly adds to the patient's comfort; a very useful form of splint is Gooch's, which encircles the limb completely. The limb should never be left without a splint, as spasmodic contractions of the hamstring muscles are certain to occur, and these are likely to give rise to permanent contractions which cannot be overcome easily.

Amputation by equal lateral skin flaps. This method is widely practised and is a very simple one, although it suffers from the liability to adherent cicatrix; the thinness of its flaps is also a drawback, and it is not uncommon for the end of the bone to project beneath and become adherent to the angle of the flaps in front.

Operation. The positions of the limb and of the surgeon are the same as in the preceding operation; a tourniquet is applied around the middle of the thigh. The level of the bone section is marked by the left thumb on the crest of the tibia, and the index finger is placed upon the corresponding point in the centre of the limb behind. The surgeon leans over the limb and commences his incision from the latter point, making a crescentic incision with its convexity downwards on each side of the limb, terminating an inch below the bone section in front (see Fig. 130). Each flap should be about an inch longer than half the lateral diameter of the limb at the level of the bone section; it is in order to obviate the

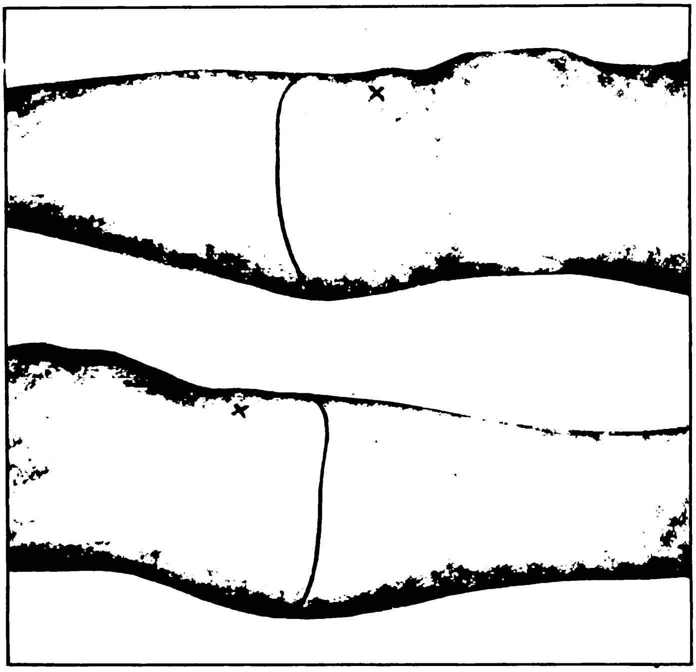

FIG. 130. AMPUTATION AT THE 'SEAT OF ELECTION' BY EQUAL LATERAL SKIN FLAPS. The X shows the level of bone section. Just below this point the muscles are divided by a circular sweep.

risk of the bone projecting between the flaps that the incisions are only made to extend up to within an inch of the line of bone section in front.

The knife is carried through the deep fascia, which is taken up with the skin until the level of the junction of the flaps in front is reached. At this point all the muscles are divided by circular sweeps of the knife, aided by the manœuvre already recommended for division of the deep muscles (see p. 335), and these structures are raised from the bone for the last inch, as there described; the remaining stages of the operation are also exactly similar.

By a large external flap (Farabeuf's method). This method is suitable for cases in which the patient is to be fitted with an artificial limb furnished with a joint at the knee instead of wearing a peg-leg. It is a valuable amputation, but certain precautions must be observed if full success is to be attained. The large external flap was in common use before Farabeuf introduced the operation called by his name, but the merit of the latter lies in the fact that the anterior tibial artery and

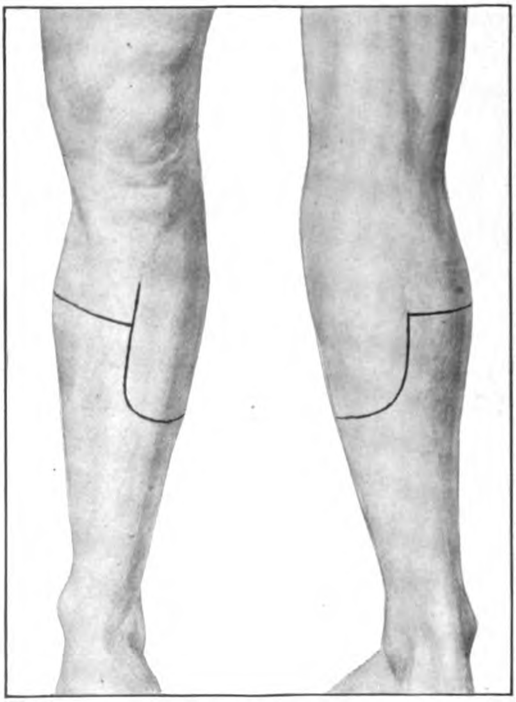

FIG. 131. INCISIONS FOR FARABEUF'S AMPUTATION AT THE 'SEAT OF ELECTION'. The drawing shows the formation of the single large external flap, the level of bone section corresponding to the upper limit of the front limb of the incision.

all the muscles are raised with the outer flap and therefore its nutrition is not interfered with, and there is no fear of the sloughing that frequently marred the older operations.

Operation. The patient is brought down until the buttocks are nearly level with the end of the table, and the assistant flexes the hip and knee joints, making the heel almost touch the buttocks, and supporting the sole of the foot on the end of the table. The surgeon stands on the patient's right of the limb to be operated upon, and marks the point at which he is going to saw the bone with his left middle finger. On the right leg the incision is carried from this spot vertically down along the inner margin of the crest of the tibia, then across the outer aspect of the limb (which is rotated fully inwards), and vertically up the

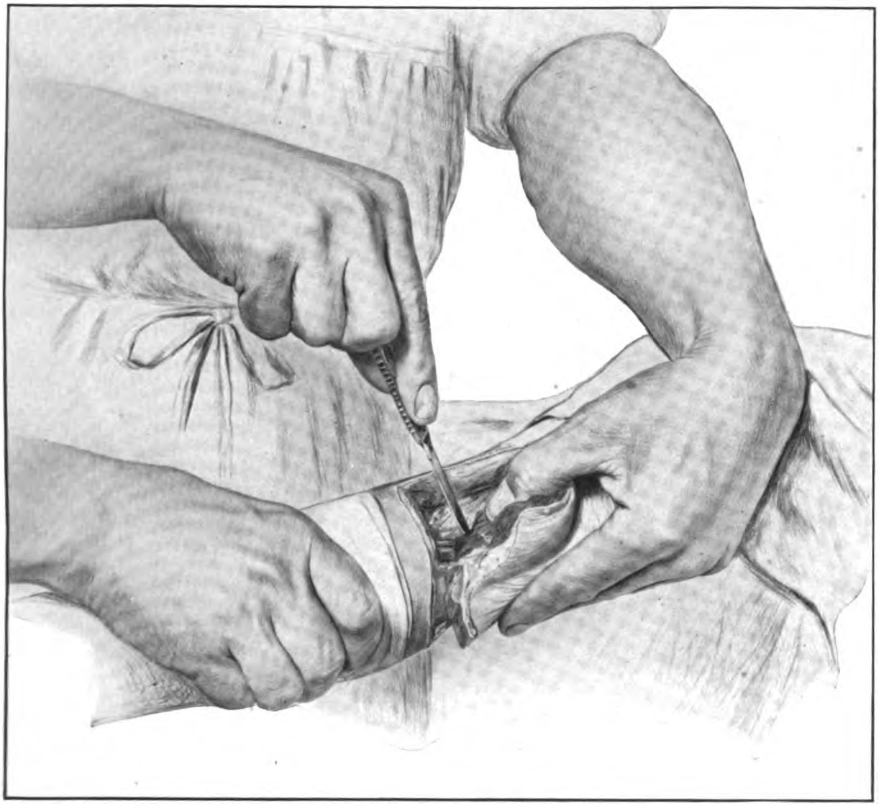

FIG. 132. DIVIDING THE STRUCTURES IN THE LARGE OUTER FLAP IN FARABEUF'S AMPUTATION AT THE 'SEAT OF ELECTION'. The soft parts are pulled away from the interosseous membrane by the left thumb, and the tissues are cut obliquely from within outwards.

middle line of the limb behind to a point one inch short of the level from which it started on the front of the leg. This incision marks out a U-shaped flap, which should be one-third longer than the lateral diameter of the limb at the level of bone section. The incision is gone over with the knife a second time so as to allow the skin to retract freely everywhere. As the last part of the incision, viz. that on the back of the leg, is being marked out, the assistant raises the limb until it is nearly horizontal.

On the left leg the procedure is different. The surgeon stands facing, and somewhat to the outer side of, the foot, which he grasps in his left hand so that he can rotate the limb in whatever direction he pleases. The points between which the incision is to run should be marked out previously either by making small nicks in the skin or by an assistant's fingers. The leg is rotated inwards and the incision is begun from the anterior aspect of the limb, carrying it down just inside the crest of the tibia as before, then across its outer surface. The limb is raised with the left hand as this is done, and, as the incision is carried up the middle line behind to the point at which it is to cease (*vide supra*), the limb is

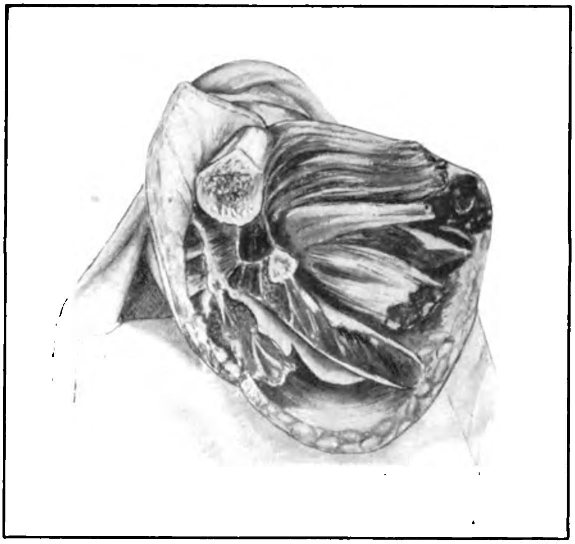

FIG. 133. FLAPS AFTER FARABEUF'S AMPUTATION AT THE 'SEAT OF ELECTION'. The large external flap with its muscles and blood-supply intact is well shown. The edge of the tibia is bevelled off.

raised higher and higher until finally it is almost vertical. The limb is now transferred to the assistant, and the surgeon takes his place on the outer side of it to complete the remaining stages of the operation, which are the same on both sides. Bending over the limb, the knife is drawn transversely across its inner aspect from the upper extremity of the posterior incision to the corresponding point on the front of the limb, viz. one inch below the level of the upper extremity of the incision there (see Fig. 131). The skin is allowed to retract to its full extent.

The deep fascia is next incised along the crest of the tibia from above downwards, the fingers of the left hand are thrust between the muscles and the bone right down to the interosseous membrane, and the tibialis anticus (anterior) pulled away from the tibia. The knife is inserted between the bone and the muscles and the latter are divided from within outwards on a level with the retracted edge of the outer flap by a succession of cuts from the deep to the superficial surface carried as far outwards as the fibula (see Fig. 132). The peronei are then divided and peeled from the fibula up to the level of the bone section. The posterior muscles are divided either by transfixion or by cutting from without inwards; in the former case the knife is entered behind the fibula and brought out through the transverse incision across the inner aspect of

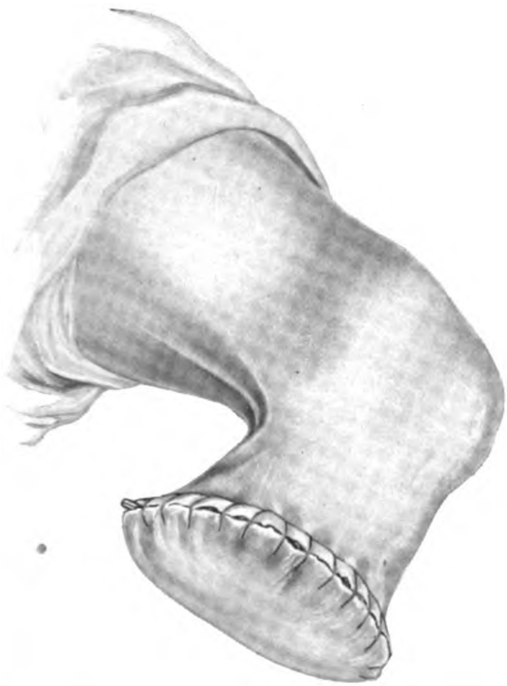

Fig. 134. Stump after Farabeuf's Amputation at the 'Seat of Election'.

the limb, the large outer flap being raised and kept out of the way as the division of the muscles proceeds.

Finally all the soft parts, including the periosteum, are peeled up from the bone for about an inch, when the level of the proposed bone section is reached. The bones are now sawn, and, if possible, the fibula should be divided on a higher level than the tibia; it should also be bevelled from without downwards and inwards, whilst the tibia should have its sharp anterior margin bevelled off in the usual way (see Fig. 133). It is rather difficult to bevel off the fibula properly, but the best way is to divide the bone transversely and reduce it subsequently to the proper shape with a chisel. On the left leg the fibula will be sawn first, while on the right it is better to saw it after the tibia has been cut through. The posterior tibial nerve is dissected out and cut short, and the large external flap is brought across the ends of the bones and sutured (see Fig. 134).

DISARTICULATION AT THE KNEE-JOINT

There is still difference of opinion as to the value of this particular form of amputation. While some authorities prefer it because it furnishes a stump with an expanded end upon which the full weight of the limb can be borne, others object to it because of its æsthetic drawbacks. The patient cannot wear an artificial limb with a false joint so comfortably or so naturally as he can when the amputation has been done through or above the condyles, because the false joint is on a lower level than the normal one, and although this is not noticeable when the patient is upright, it is unmistakable when he sits down. On the other hand there is no doubt that the large-ended stump resulting from a disarticulation allows the weight of the body to be borne directly upon its end with greater certainty and comfort than is always the case after amputation through or above the condyles. In the latter case the stump may be found to be incapable of bearing pressure at all, and the artificial limb may have to take its purchase from the pelvis. As a general rule, therefore, it may be suggested that disarticulation through the knee is more suited for the working classes, whereas amputation higher up should be done for those who can afford a more expensive apparatus, and whose chief desire is to secure the best æsthetic result.

Various methods may be employed for disarticulation. The one most used in England is that known by the name of Stephen Smith. The only other one that needs description is the elliptical method, which is very simple and gives a sound and useful stump; it is very similar to Stephen Smith's.

Stephen Smith's disarticulation at the knee-joint. The amputation originally introduced by Stephen Smith (*New York Journal of Medicine*, September, 1852) was by means of what he termed 'a hooded flap'; in other words, one marked out by an oblique racket incision. In order to make a neater stump, however, English surgeons are in the habit of slightly modifying the incision by cutting a V-shaped portion out of the front of the hooded flap, and thus converting the amputation into one by two lateral flaps of an irregular shape.

Operation. The lower half of the thigh projects well beyond the edge of the table. The surgeon stands on the patient's right of the limb to be operated upon; the other is fastened down to the table out of the way. The level of the knee-joint is defined by flexing and extending the limb, and the surgeon places his left forefinger in the middle line behind upon a level with the joint line. The thumb rests upon the lower part of the tubercle of the tibia. The incision is commenced behind by leaning over the limb and entering the point of the knife immediately below the tip of the forefinger, the limb being rotated towards the

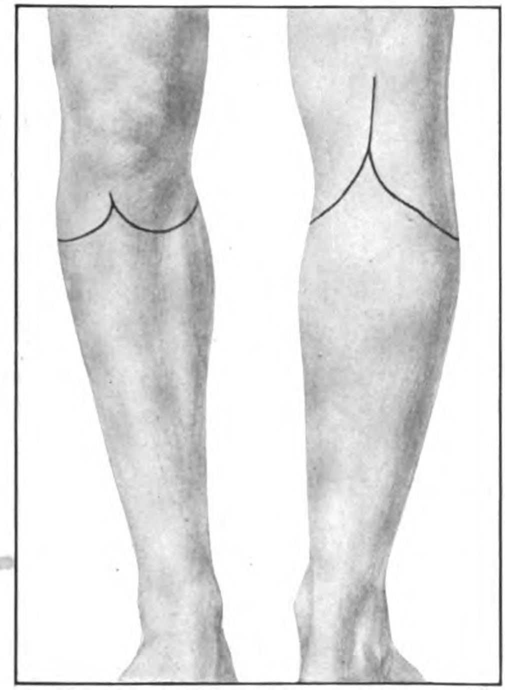

FIG. 135. INCISION FOR STEPHEN SMITH'S DISARTICULATION AT THE KNEE-JOINT. It will be noted that the incision extends slightly lower down on the inner than on the outer side.

operator so as to bring the posterior surface as much into his view as possible. The knife is carried down vertically in the middle line for three inches, and is then made to cut a lateral flap with its convexity downwards, the lowest point being a full inch below the tubercle of the tibia. As it approaches the middle line in front the incision is carried just up to the point of the thumb, which is on the lower part of the tubercle of the tibia. The limb is then raised somewhat and rotated in the opposite direction, *i.e.* away from the surgeon, who cuts the other lateral flap from the tubercle back to the vertical median incision at the

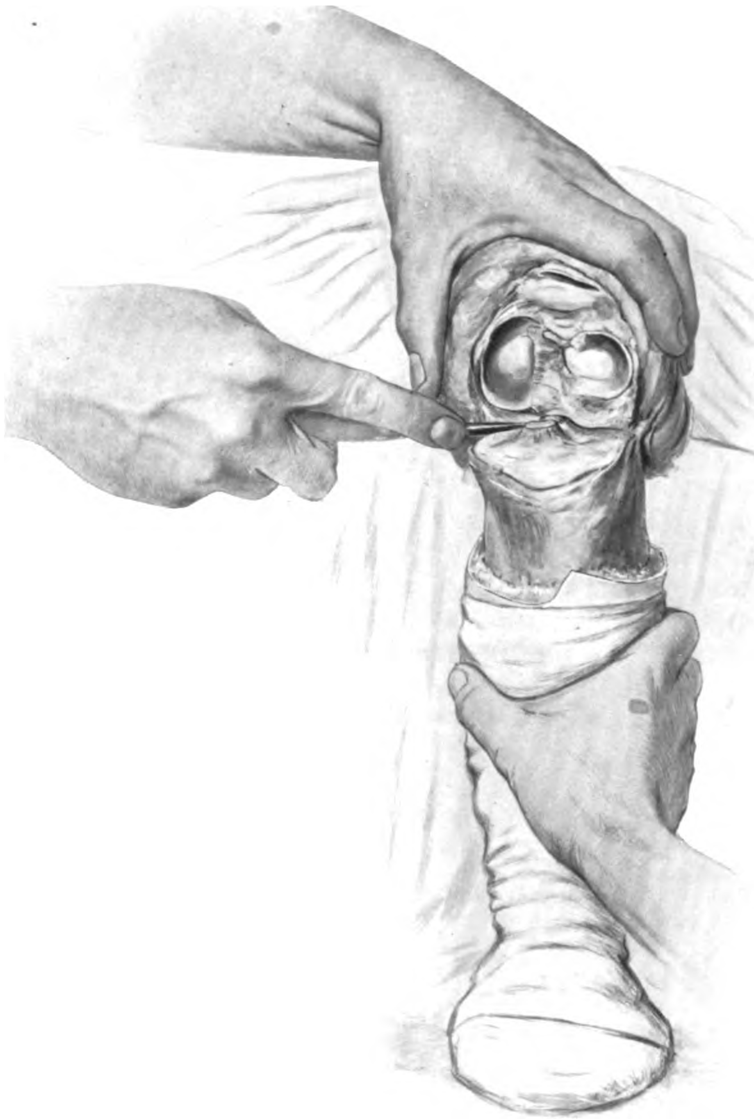

FIG. 136. DISARTICULATION OF THE KNEE-JOINT BY STEPHEN SMITH'S METHOD. The semilunar cartilages are seen in contact with the condyles of the femur. The knife is dividing the posterior ligament of the knee-joint and the popliteal vessels.

point where the opposite lateral incision began, namely, about three inches from its commencement (see Fig. 135). It is generally advised that the inner flap should be a little longer than the outer in order to cover the large inner condyle satisfactorily.

The skin is pinched up in the fingers, the incision is carried through the deep fascia, and the flap on each side is dissected up to the level of the ligamentum patellæ. When this level is reached, the knife is carried down to the bone all round and the ligamentum patellæ is divided; the assistant, who has previously held the limb horizontal, now flexes the knee, whilst the surgeon insinuates his knife between the semilunar cartilages and the tuberosities of the tibia so as to separate these two structures and leave the cartilages applied to the condyles of the femur. The knee is then bent still further, and the crucial ligaments are divided with a few touches of the knife. Disarticulation is completed by retracting the flaps fully, passing the knife across the joint, between the tibia and the femur, and then extending the limb almost completely and cutting down towards the floor. This divides the posterior ligaments and the structures in the popliteal space (see Fig. 136).

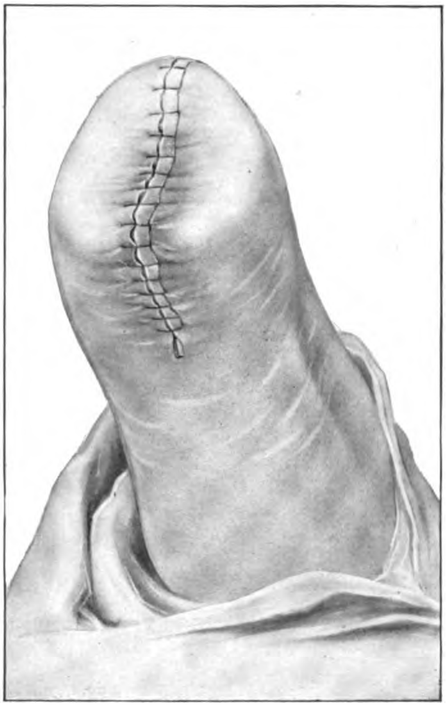

FIG. 137. STUMP LEFT AFTER STEPHEN SMITH'S DISARTICULATION AT THE KNEE-JOINT.

The only vessels of importance that require ligature are the popliteal vessels and some of the articular branches. The internal popliteal nerve should be isolated, and an inch of it excised. When brought together, the flaps form a vertical cicatrix in the hollow between the condyles (see Fig. 137), and are secured by a few coaptation sutures of silkworm-gut, with a continuous suture to unite the skin edges. A drainage tube is inserted at the upper end of the incision. The limb is placed upon a straight back-splint or in a roll of Gooch's splinting, and raised on pillows to an angle of 45°; it should be fastened between sandbags so as to prevent spasmodic jerkings of the stump. The bandage fastening on the dressings should be a figure-of-eight round the pelvis: the splint should also be secured by a similar bandage, otherwise the splint and the dressing are very apt to slip off the stump. The drainage tube, which is in the most dependent part of the wound, should be removed at the end of forty-eight hours. The sutures may be taken out at the end of fourteen days, when the patient can also dispense with the splint. There is usually some pain referred to the sciatic nerve for the first few days after the operation, but this is easily relieved by opium. The stump can bear considerable pressure in about a month.

The operation furnishes a perfect stump; the cicatrix is vertical and gets drawn up into the inter-condyloid notch out of the way of all pressure, while the semilunar cartilages, which are left behind in contact with the condyles, serve to square off the end of the stump and fit it admirably for bearing the weight of the body. The only objection to the operation is that common to all disarticulations at the knee-joint, viz. that the instrument maker has to fit the patient with a limb in which the level of the artificial knee-joint is lower than that on the sound side and therefore he prefers an amputation through the condyles.

Difficulties. The chief mistake made in this operation is the very serious one of cutting the flaps so that they cannot be made to cover the condyles of the femur. It is a common fault when operating on the living, and more particularly on the dead subject, to begin too high up, and to trace out a racket incision of the lanceolate type rather than of the well-known crupper form (see Fig. 138). In the former the ends of the incision begin to diverge from one another above the level of the lower ends of the condyles, and the result is that the skin cannot be made to meet and to cover the condyles without too much tension. It is of the greatest importance to begin the incision at the level of the joint, and to make the first three inches of it vertically in the middle line behind, so as to form a definite handle to the racket; this ensures ample covering for the large condyles of the femur. If the flaps are found to be faulty in this respect at the end of the operation there is no alternative but to make a trans-condyloid section of the femur.

By an oblique elliptical incision. The positions of the patient and the surgeon are the same as before. The left thumb marks the lowest point of the elliptical incision, which should cross the anterior border of the tibia a full diameter below the level of the joint, which must be defined carefully (see p. 343). The highest point of the ellipse should cross the middle line of the calf half that distance below the joint line; in estimating these measurements it is well to err on the side of amplitude in order to allow for the retraction of the soft parts. An elliptical incision is made around the limb, its long axis being at an angle of 30° to the vertical (see Fig. 139). The skin is allowed to retract, and then the skin and fascia are freed from the deeper structures by a few touches of the knife, and the front part is turned up as a sort of cuff, its free edge being seized between the thumb and fingers of the left hand. The deep fascia should be taken up with the skin so

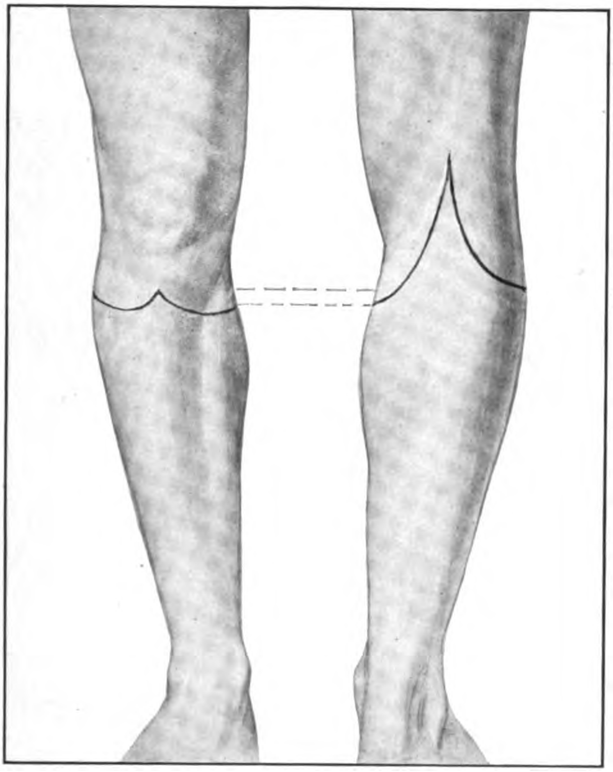

FIG. 138. FAULTY INCISIONS FOR STEPHEN SMITH'S DISARTICULATION. The incision behind begins to diverge at once, and the result of this is that there will not be enough covering for the condyles of the femur.

as to maintain the blood-supply of the flap intact. The anterior part of the flap is raised until the lower end of the patella is reached, and then the limb is moderately flexed, the ligamentum patellæ is cut across, and the joint opened. The remaining steps of the operation are similar to those of Stephen Smith's amputation, and the semilunar cartilages can be left in contact with the condyles of the femur as in that operation. The wound is sewn up so as to form a cicatrix which is parallel to the transverse diameter of the limb, so that the stump appears to have been fashioned with antero-posterior flaps.

There are many other methods of disarticulating, but the two given above will suffice for the cases usually met with. Of these Stephen Smith's is the better, but the elliptical incision method is described as being one in which there is less likelihood of a beginner cutting faulty flaps. The operations by a long anterior flap are more suited to the

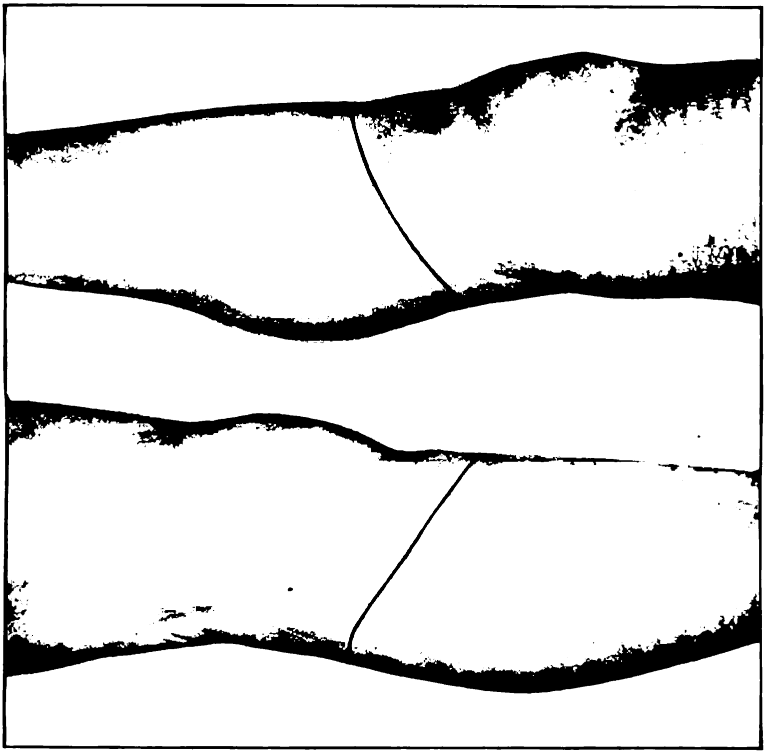

FIG. 139. DISARTICULATION THROUGH THE KNEE-JOINT BY AN OBLIQUE ELLIPTICAL INCISION. The cicatrix gets pulled well up into the inter-condyloid notch.

next group of cases, in which the amputation is practised through or above the condyles.

TRANS-CONDYLOID AND SUPRA-CONDYLOID AMPUTATIONS

The merits of these operations have been discussed already (see p. 342). The stump is shorter and the base of support is smaller, and therefore the chance of bearing the whole weight of the body directly on the end of the stump is not quite so good as it is in the case of disarticulations, and the artificial limb may have to take its purchase from the pelvis. In order to facilitate weight-bearing the condyles should be divided as low down as possible; when the femur is sawn through the base of the condyles the articular surface of the patella may be cut off and its cut surface turned up and made to unite with the cut surface of the femur so as to give a rounded end to the stump and one well calculated to bear pressure. In all cases every attempt should be made to save the adductor tubercle, as the maintenance of the functions of the adductors is an enormous gain to the patient. The action of the quadriceps should be also retained, either by saving the patella or by suturing its tendon to the bone. Of the amputations commonly practised in this situation only three will be described: (i) The operation by long anterior and short posterior flaps, (ii) Lister's modification of Carden's operation, and (iii) The Stokes-Gritti amputation. All three amputations are useful under certain circumstances.

Amputation by long anterior and short posterior flaps. The limb is drawn well over the table and the surgeon stands on the patient's right of it, the sound leg being fastened down out of the way. The limb being held almost horizontal, a long anterior flap is marked out commencing just behind the condyle on the side away from the surgeon and immediately above the level of the joint; the limb is rotated towards the surgeon while this is being done. The incision is carried vertically down for rather more than the antero-posterior diameter of the limb at the point of bone section, and the leg is then rotated away from the surgeon, who draws the knife across the front of the limb and finally up along the lateral aspect of the limb facing him, until it reaches a point opposite that from which it started on the other side (see Fig. 140). A large U-shaped flap is thus marked out and is allowed to retract fully by deepening the incision uniformly through the deep fascia all round. A posterior flap is next marked out by passing the arm beneath the limb and cutting transversely across its posterior surface from one side of the anterior flap to the other, half-way between the point of bone section and the lower limit of the anterior flap. The edges of the latter are then seized between the left thumb and forefinger, and it is raised, along with the deep fascia, well above the patella. When the upper edge of this bone is reached a circular sweep is made around the limb, dividing the soft parts down to the bone and opening the knee-joint. A second sweep divides all the periosteal structures, and the saw is then applied to the condyles just above the upper limit of the cartilaginous surface. The saw should not be applied quite at right angles to the long axis of the bone, but at a slight angle, so as to cut a little lower on the inner side than the outer, and thus reproduce the normal obliquity of the condyles.

The long anterior flap folds over the end of the bone, and the cicatrix falls well on to the posterior aspect of the limb. The flaps are united by deep coaptation sutures of silkworm-gut reinforced by a continuous suture for the edges. A drainage tube is necessary for the first three days or more. The dressing is applied first on the anterior surface

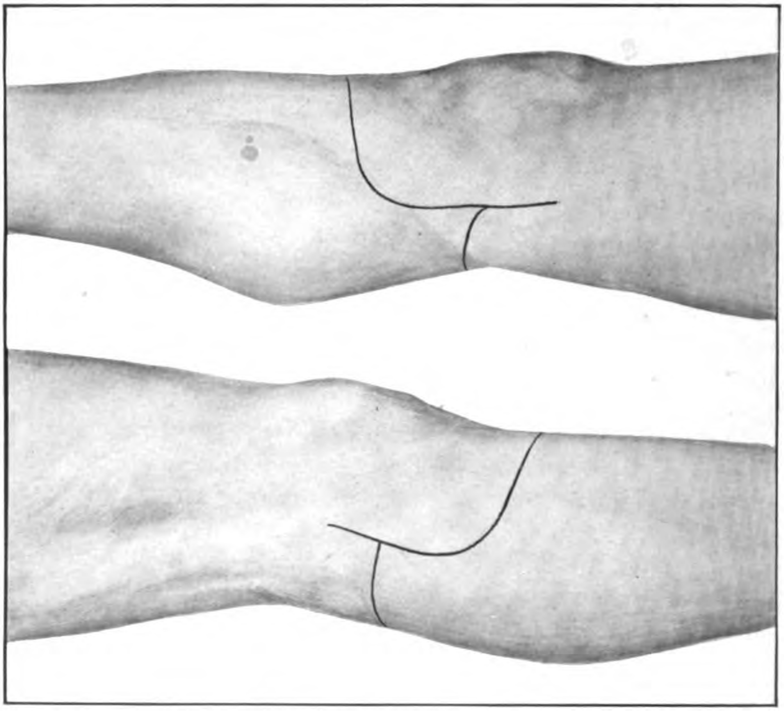

FIG. 140. TRANS-CONDYLOID AMPUTATION OF THE FEMUR BY LONG ANTERIOR AND SHORT POSTERIOR FLAPS.

of the limb, then carried across the end of the stump, and finally up on the posterior surface.

The stump given by this operation is not so capable of bearing the patient's full weight for a long time as are those resulting from the preceding operations.

Lister's modification of Carden's operation. Lord Lister has devised the following useful modification of Carden's amputation in which only a long anterior flap was fashioned (Holmes's *System of Surgery*, vol. iii, p. 718). He describes it as follows:—

'The only objection to Carden's operation, as described by him, is the occasional occurrence of more or less sloughing of the long anterior flap of the skin, in spite of faultless operating. It is plain that the risk of sloughing would be diminished if the flap could be made shorter by not carrying the horns of the incision, by which it is formed, so high up the limb; and I found that it is by no means difficult, when the parts are in their natural condition, to accomplish the operation without mak-

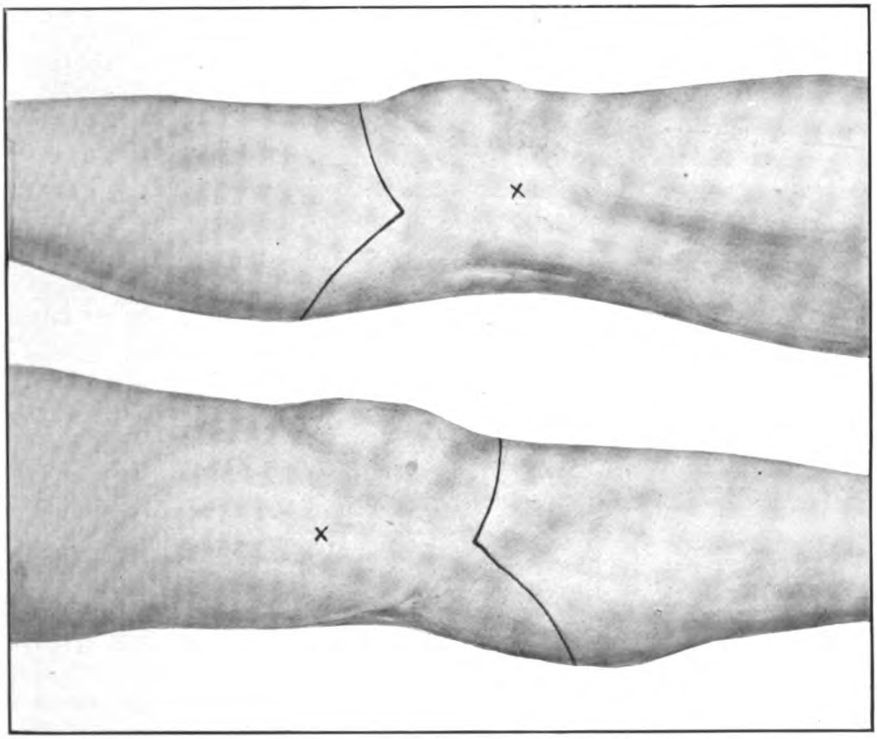

FIG. 141. INCISIONS FOR LISTER'S MODIFICATION OF CARDEN'S AMPUTATION.
The × shows where the condyles are divided.

ing any anterior flap at all, the integuments in front being divided transversely at the level of the lower end of Mr. Carden's flap. I also found it advantageous to form a short posterior skin flap, both for the sake of coaptation of the cutaneous margins without puckering and as a useful addition to the covering for the end of the stump (see Fig. 141).

'The operation is performed as follows. The surgeon first cuts transversely across the front of the limb from side to side at the level of the anterior tuberosity of the tibia, and joins the horns of this incision posteriorly by carrying the knife at an angle of 45° to the axis of the leg through the skin and fat. The limb being elevated, he dissects up the posterior skin flap, and then proceeds to raise the ring of integument as in a circular operation, taking good care to avoid scoring the subcutaneous tissue; and, dividing the hamstrings as soon as they are exposed, and bending the knee, he finds no difficulty in exposing the upper border of the patella. He then sinks his knife through the insertion of the quadriceps extensor, and having cleared the bone immediately above the articular cartilage and holding the limb horizontal, he applies the saw vertically and at the same time transversely to the axis of the limb (not of the bone), so as to ensure a horizontal surface for the patient to rest upon. The popliteal artery and vein are then secured, and any articular or other small branches that may require it.

'When the soft parts are thickened and condensed by inflammation, the integuments cannot well be reflected above the patella with such incisions of the skin. But the difficulty may be got over by cutting into the joint as soon as the ligamentum patellæ is exposed, and at once removing the leg by dividing the ligaments and hamstrings; after which the soft parts can be retracted from the femur sufficiently to permit the application of the saw. The arteries having then been secured, the patella is dissected out at leisure.

'As thus performed, Carden's operation takes a little more time and pains than when the integument is divided in the form of an anterior flap; but these are well rewarded by the ample covering for the bone, the small external wound, and the perfect security against sloughing.'

The Stokes-Gritti amputation. The positions of the surgeon and the patient are the same as in the previous operation. A large rectangular anterior flap is marked out by an incision running from a point just above the base of the condyle on one side to the corresponding point on the opposite side, and reaching as low as the upper part of the tubercle of the tibia. The posterior flap is one-third the length of the anterior, and is made by drawing the knife transversely across the back of the limb. The anterior flap is raised, the ligamentum patellæ being cut across when it is met with, the knee-joint opened and the capsule divided so as to allow the patella to be raised with the flap. The tendons at the back of the joint are divided on a level with the edge of the retracted skin, and the posterior flap is raised to the level at which the bone is to be sawn, which is about an inch above the base of the condyles, through the expanded portion of the shaft of the femur and below the medullary cavity. A circular sweep is made with the knife around the bone at this spot, the periosteum is divided and the femur is sawn.

The surgeon now carries his knife around the circumference of the patella along the margin of the cartilage so as to cut a groove, and, grasping the flap firmly between the left thumb and forefinger, he stretches the subcutaneous surface of the bone against the dorsal aspect of the remaining fingers of his hand (see Fig. 142), and removes the cartilaginous surface with a saw. The bony surface left will correspond closely in size to the cross section of the divided femur (see Fig. 143), and the two surfaces are placed in apposition and fastened together

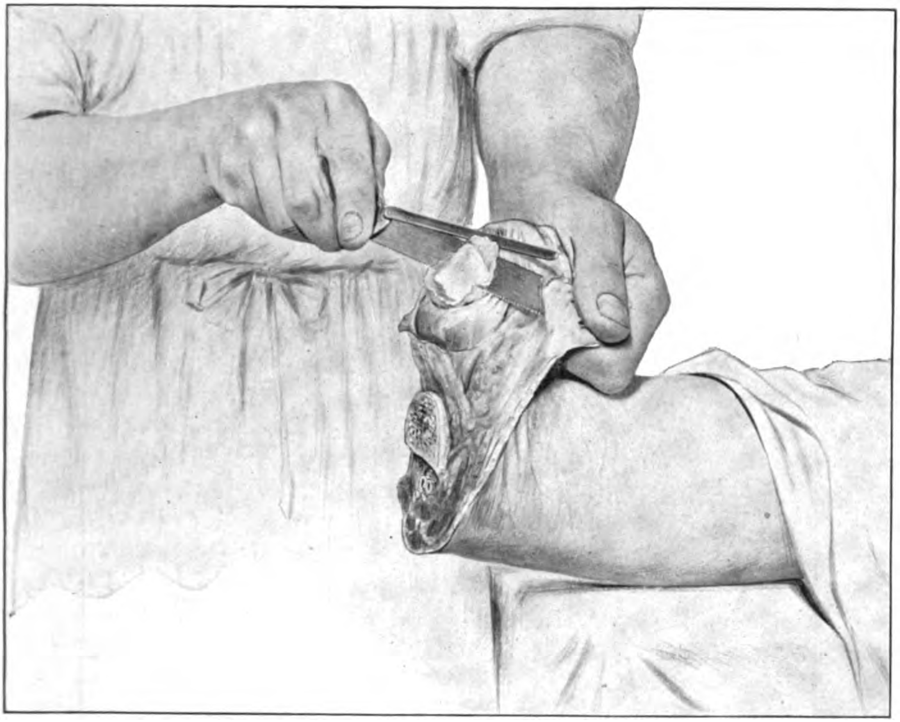

FIG. 142. REMOVING THE ARTICULAR SURFACE OF THE PATELLA IN THE STOKES-GRITTI AMPUTATION.

either by stout sutures passed through the soft parts or by some form of fixation pegs or pins; the patella thus furnishes a rounded end to the divided femur upon which the patient can bear his weight.

The anterior flap is turned down round the lower end of the femur; the cicatrix is transverse and lies just above the line of bone section. A drainage tube is inserted at each angle of the wound, and the dressings are applied to the front of the thigh first, then carried round the end of the stump and up the posterior aspect of the limb, so as to keep the patella firmly in apposition with the femur.

This amputation is really supra-condyloid, whereas both the preceding methods are trans-condyloid. The advantage of the amputation just described is that the two surfaces of bone correspond closely in size, whereas in Gritti's original amputation the section was made through the condyles, where the cut surface of the femur is much larger than that of the patella, and, owing to this and to the increased length of the

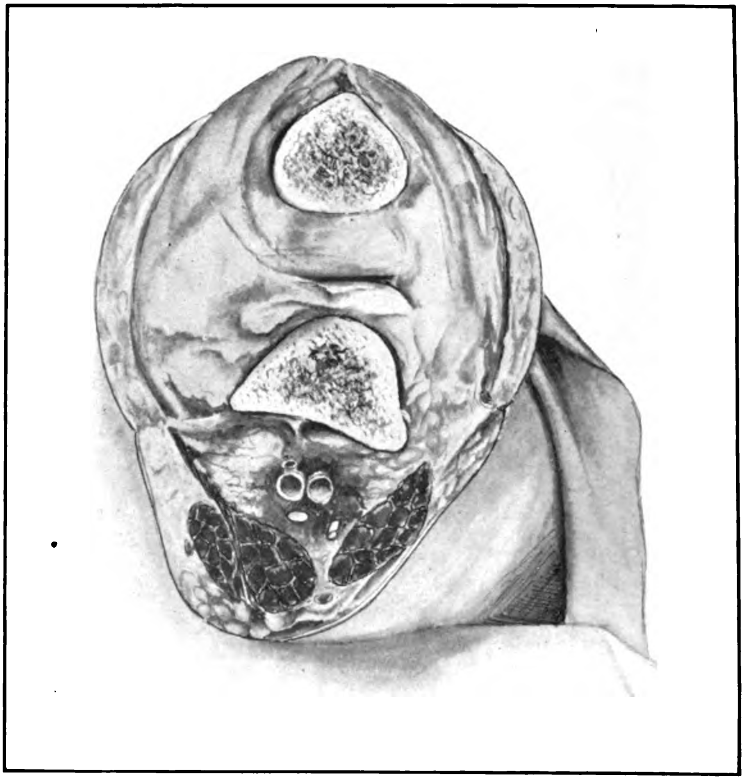

FIG. 143. THE FLAPS AFTER A STOKES-GRITTI AMPUTATION. It will be seen how nearly the sawn surface of the patella and the supra-condyloid region of the femur correspond in size.

femur, it was difficult to get and maintain the patella in apposition with the end of the femur.

The Stokes-Gritti amputation is a valuable one, and should be preferred to an amputation through the shaft of the bone whenever circumstances allow of its being done. In the majority of cases the stump will bear the body weight upon its end, whereas this is hardly ever the case in amputations through the shaft of the bone, the artificial limb taking its purchase from the pelvis in the latter cases. The medullary canal is not opened, the muscular attachments are disturbed very little, and the adductors retain their connexions and act satisfactorily. There is little chance of a conical stump resulting, as so few of the muscles are severed from their attachments.

At the same time the stump is not always satisfactory. In former days especially, bony union did not always take place between the patella and the end of the femur, and the former became tilted and formed a projection that gave rise to pain when weight was borne on the end of the stump. This, however, is hardly likely to happen now, since the methods of fastening bone surfaces together have been greatly improved. The method that I have found most satisfactory on the whole is to drive a square ivory peg through the patella into the end of the femur, allowing its free end to protrude through a hole in the skin over the patella. This is surrounded by the dressings, and can be removed on the tenth day. The use of a removable peg is adopted because pressure is borne direct upon the anterior surface of the patella and any foreign body such as a wire, nail, or screw permanently embedded in that bone may give rise to irritation from pressure and require removal.

I have seen effusion occur in the prepatellar bursa after the patient has been getting about, necessitating excision of the bursa. Should the patella be larger than the cut end of the femur to which it is to be applied it should be pared down until it fits fairly accurately.

CHAPTER VIII

AMPUTATIONS THROUGH THE THIGH AND DISARTICULATIONS AT THE HIP-JOINT

AMPUTATIONS THROUGH THE THIGH

MANY methods are available for amputation in this region, the only thoroughly unsuitable one being that by a large posterior flap; this is objectionable because of the inveterate tendency of the hamstring muscles to retract. The most satisfactory method on the whole is by long anterior and short posterior flaps consisting of skin and a gradually increasing amount of muscle. This, and the circular amputation, which is most suitable for cases in which it is imperative to divide the bone as near the level of the injured tissues as possible, are the only two that will be described here, although it must be understood that a large number of other amputations can be performed, and should even be preferred to the two described under varying circumstances, depending upon the seat of injury, the state of the tissues, &c.

Above the condyles all the length possible should be saved as the possibility of end-bearing decreases rapidly as the upper limit of usefulness as regards leverage is reached. A stump in which the bone is less than 3 inches, measured from the pubis, is of little value, and exarticulation is preferable. The linea aspera requires attention in the same manner as the crest of the tibia. It is now possible to fit an exarticulation of the hip with a very satisfactory appliance; in some cases the gait is even better than with the shorter stumps.

The circular amputation. This is circular only in name; it is really an elliptical amputation, because the retraction of the hamstring muscles is so great that the incision must reach considerably further down on the posterior surface of the limb than on the anterior in order to make the cut edge of the skin horizontal all round the limb. It is only suitable for the lower third of the limb, where there are a number of tendons that retract well out of the way; higher up, the large muscular masses are more difficult to cut so as to ensure a good stump.

Operation. The patient is drawn down so that nearly the whole of the thigh projects beyond the end of the table, a tourniquet is applied transversely round the limb just below the fold of the groin, and the other leg is fastened down out of the way. The surgeon stands on the patient's right of the limb to be operated upon, and grasps the limb at the level of the bone section with one hand and makes an oblique circular incision round the limb at such a distance below this point that the highest point of the incision in front is equal to a quarter of the circumference of the thigh at the point of bone section: this will be four to five inches in an ordinary limb. The hand is passed beneath the limb, which is rotated away from the surgeon as far round as possible, so that the heel of the knife is near the junction of the anterior with the outer surfaces. The incision is marked out by drawing the knife gently round the limb from heel to point until the circular cut is complete (see Fig. 63). This may be done in one single sweep, or in two, if necessary; in the latter case the knife is carried in the reverse direction, joining the commencement of the first incision to its termination. After the incision has been made, it is deepened evenly through the fascia all round so that the skin can retract fully. From what has been said before, it will be remembered that the incision through the skin at the back of the thigh will be nearly two and a half inches lower down than that on the front.

The cut edge of the skin is seized in the left thumb and index finger and raised for about four inches all round by circular sweeps of the knife which divide the bands of subcutaneous fibrous tissue put on the stretch as the skin is raised. The knife should be kept strictly at right angles to the surface as this is done. This allows the skin to be pulled back for three or four inches.

The knife is now swept around the limb through the superficial muscles in close contact with the retracted skin, and after these have been thus divided and have retracted, the deeper ones are divided by another circular sweep of the knife as near the proposed point of bone section as possible; finally the bone is cleared up to the point at which it is to be divided, and sawn in the usual way. It is well to bevel off the linea aspera with the saw or a chisel (see Fig. 144).

It is not always possible to do the operation exactly as it is described above. In muscular subjects and when there is inflammatory effusion or œdema in the neighbourhood of the operation, the soft parts cannot be retracted as easily as the above description would lead one to expect. In these cases, therefore, it will be necessary to raise and turn back the skin and deep fascia for the first three inches or more. This may be done in the form of a cuff, but if there be any difficulty in doing this it is better to make two short lateral vertical incisions upward from the circular incision, and thus convert the amputation into one by equal antero-posterior flaps.

The flaps are brought together and united as antero-posterior flaps, so that the cicatrix is transverse. A large drainage tube is inserted at the inner end of the incision. Few vessels will require to be secured besides the femoral artery and vein. When the amputation is performed low down in the thigh the anastomotica magna (genu suprema) must be tied; when higher up, the profunda and the perforating arteries.

FIG. 144. BEVELLING THE LINEA ASPERA IN AMPUTATION THROUGH THE FEMUR. The soft parts are kept back with a two-tailed linen retractor, and the linea aspera is shown bevelled off.

Amputation by long anterior and short posterior flaps. The positions of the patient and the surgeon are the same as in the previous operation. If the amputation is to be performed at or below the middle of the thigh, a tourniquet should be applied horizontally around the limb just below the groin; should it be necessary to amputate higher than this, however, the tourniquet should be put on as for disarticulation at the hip (see p. 363); if applied otherwise the parts cannot retract properly, owing to the compression of the tourniquet. In connexion with this form of amputation it should be remembered that when the bone is sawn at or above the junction of the middle with the lower third, the femoral artery lies exactly beneath the junction of the anterior with the posterior flap, and that therefore it is liable to be split longitudinally by the knife. This is not a really serious objection provided that the surgeon makes a complete circular incision through the muscles down to the bone at the level at which he is going to saw the latter, but in order to avoid this difficulty the flaps are often raised from the antero-external and postero-internal aspects of the limb rather than from the true anterior and posterior surfaces; that is to say, the point at which the knife is entered on the inner side of the limb is shifted outwards about an inch and a half, and the other extremity of the incision is correspondingly altered. It was not uncommon to slit the artery longitudinally when it was the fashion to cut the flaps by transfixion, but such an accident is hardly likely to happen with the present-day method of cutting the flaps from without inwards.

The left forefinger and thumb mark out the terminal points of the incision on a level with the point of bone section. A large U-shaped flap, in width equal to full half the circumference of the limb and in length the full antero-posterior diameter of the limb at the point of bone section, is now marked out through the skin and deep fascia in the usual way. When the amputation is to be done through the lower third of the femur this will bring the incision well down over the patella. The incision is commenced by leaning over the limb, which is rotated to expose its lateral aspect properly to the knife; when finishing the incision, the limb is rotated away from the surgeon. It is best to use a comparatively short amputating knife, one of six inches being quite long enough, and to mark out the incision, not with the point of the knife, but by drawing it along the limb with a gentle sawing movement, using as much as possible of the cutting edge.

The short posterior flap is marked out by passing the arm beneath the thigh, which is raised by the assistant, and by cutting a flap rather more than one-third the length of the anterior (see Fig. 145). These incisions are carried down through the deep fascia, and the skin is allowed to retract fully. The edge of the anterior flap is now pinched up between the left thumb and forefinger, and is raised by a few gentle sweeps of the knife across the limb, at first taking up only the deep fascia, but afterwards, when the quadriceps muscle is reached, gradually taking up more of the muscle until the knife has been carried down to the bone when the level of the proposed bone section is reached (see

Fig. 146). This flap is given to an assistant, who holds it back whilst the posterior one is raised. In this case the tissues are cut almost directly down to the bone at the level of the retracted skin, the line of incision being obliquely upwards; while this is being done, the limb should be raised almost to the vertical. When the amputation is in the lower third of the femur the posterior flap may be cut by transfixion, as there are only tendons to be divided. The flaps are retracted by a two-tailed

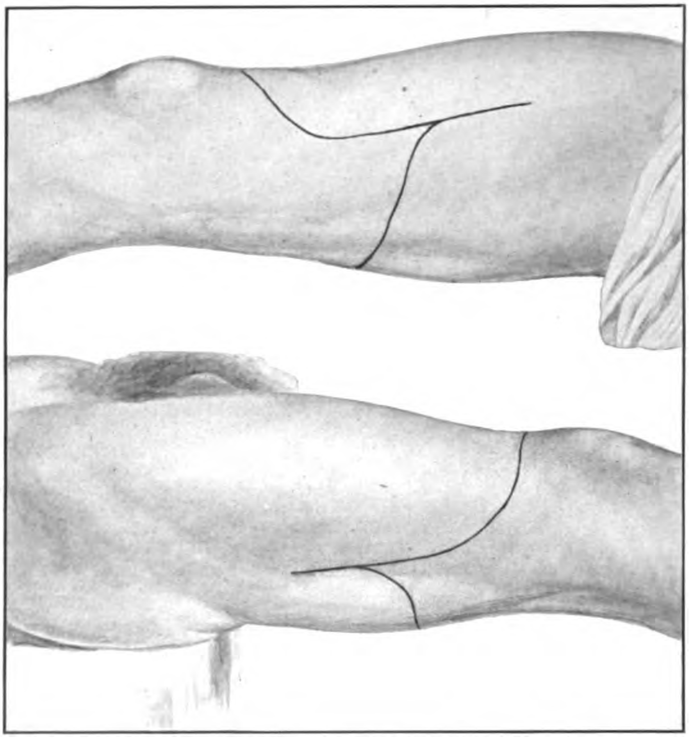

FIG. 145. AMPUTATION THROUGH THE MIDDLE OF THE THIGH BY UNEQUAL ANTERO-POSTERIOR FLAPS. These flaps are really antero-external and postero-internal in order to avoid slitting the femoral artery.

retractor (see Fig. 144), and the division of the soft parts is completed by a circular sweep of the knife down to the bone; the periosteum is retracted from the muscles for half an inch or more and the bone sawn, the linea aspera being rounded off as already described (see Fig. 144).

After the operation the femoral artery will have to be ligatured, and will probably be found in the posterior flap, except when the amputation is done in the upper third of the thigh, when it will be in the anterior one. The other vessels divided are the same as those met with in the previous operation.

A large drainage tube should be inserted at the outer angle of the wound and removed at the end of three days. The limb should be surrounded by Gooch's splinting, flexed at the hip and placed upon a pillow; the bandages securing the dressings and the splint must pass round the pelvis, as otherwise the limb may be drawn right out of the

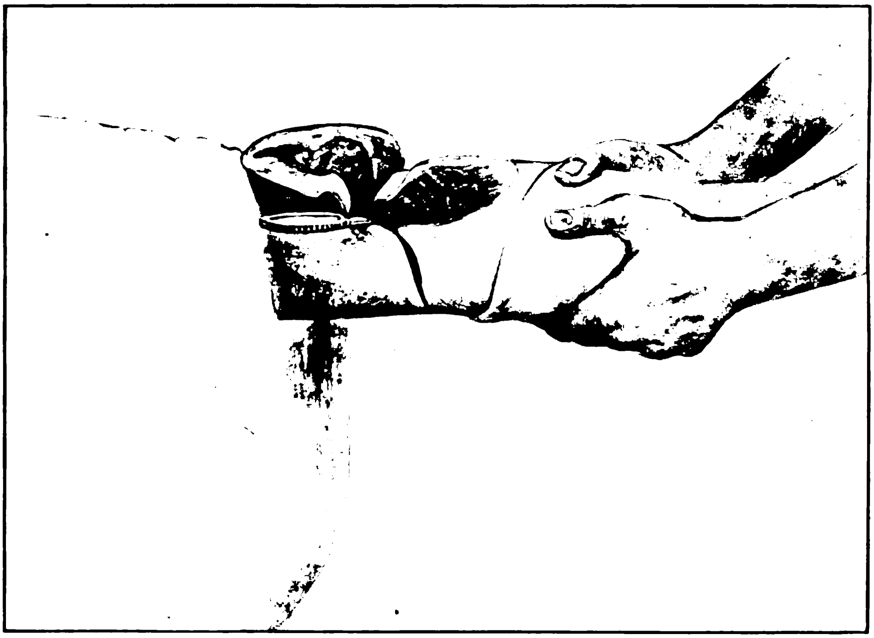

FIG. 146. CUTTING THE POSTERIOR FLAP BY TRANSFIXION IN AMPUTATION THROUGH THE LOWER THIRD OF THE THIGH. The anterior flap with its gradually increasing amount of muscle is shown reflected. The incision for the posterior flap has been made through the skin, and the knife is shown transfixing the tissues behind the femur.

dressings. Deep stout silkworm-gut sutures will be required to keep the heavy flaps in position, and it is always well to retain these, if possible, for at least a fortnight, the continuous suture being left in for about three weeks.

The result of this amputation is usually good if a fair amount of muscle has been left in the flap. A conical stump, however, is not uncommon after amputation of the thigh, especially when it is done low down. This is largely due to the great contraction of the posterior muscles.

DISARTICULATION AT THE HIP-JOINT

When a disarticulation at the hip-joint has to be performed, the immediate risks of the operation, namely death from shock and hæmorrhage, have always to be carefully considered. The lower the division of the main nerve trunks and vessels can be practised, the less do these risks become. Another point of importance not to be lost sight of is that the amputation should be so planned that the wound is removed as far as possible from the perineum and the anal region. It is always necessary to employ drainage in these cases, and when a drainage tube has to be inserted in regions so adjacent to sources of sepsis as they are here, the risk of infection is very great. Lastly, it is important to consider the question of the suitability of the future stump for bearing pressure. In all disarticulations at the hip-joint the weight is borne by the pelvis, but the longer the stump of soft parts left, the firmer the apparatus fits and the less likelihood there is of its slipping.

For all these reasons some form of the operation known in England as Furneaux Jordan's is to be preferred whenever it can be adopted. This operation consists essentially in amputating as low down as possible through the thigh, and then enucleating the upper end of the femur from the soft parts. This part of the operation may be performed at a later period.

By adopting this method the shock is diminished, as the nerves are divided at a comparatively low level, the control of hæmorrhage is easier, as it is possible to maintain an elastic tourniquet in position until all the principal vessels have been secured, and the risk of subsequent sepsis is diminished, as the wound is well to the outer side of the limb, and the risk of septic contamination from the genital region is considerably lessened. The stump is good and is longer than that left after the other operations. Therefore it should always be performed, if possible.

Indications. Disarticulation at the hip-joint may be required for the following conditions:—

(i) *For injury,* generally in the form of gunshot wounds or very extensive crushes, such as those resulting from machinery accidents. In most cases of injury it is possible to save a certain amount of the femur, and this should always be done, if possible, as it adds greatly to the strength of the resulting stump and an artificial limb is more easily worn. Disarticulation will be required, however, in those injuries when the neck of the bone is shattered.

(ii) *For growths of the femur.* All sarcomata of the femur, with the exception of myeloid tumours of the lower end of the bone, call for complete removal of the femur, and a disarticulation at the hip-joint is therefore necessary.

(iii) *After failure of excision of the hip for tuberculous disease.* It is not uncommon for profuse suppuration, with commencing lardaceous disease, to persist in spite of excision of the hip. In these cases removal of the limb not only favours satisfactory drainage, but enables the surgeon to get freer access to the tuberculous mischief in the acetabulum or the pelvis, and a cure not infrequently results.

Choice of operation. In all cases in which it can be practised the operation known as Furneaux Jordan's, or some modification of it, should be employed. The diminution in the immediate mortality from shock and hæmorrhage is very striking. It is only when the soft parts are too much damaged or when they are encroached upon by a growth that any of the other amputations should be adopted.

Methods of controlling hæmorrhage during the operation. The sources of bleeding in these amputations are numerous; in front are the superficial and deep femoral vessels, while behind are the large gluteal artery and the smaller sciatic, as well as the considerable circumflex vessels on the inner and outer sides. It is this free arterial supply that makes the risk of hæmorrhage so great, and it is therefore a matter of importance to adopt the best way of preventing it. In Furneaux Jordan's amputation it is possible, should the surgeon desire it, to command the circulation during the first part of the operation by means of a circular india-rubber bandage applied horizontally round the thigh below the groin; but this only suffices until the vessels have been secured after the circular part of the amputation, and has to be removed while enucleation of the upper end of the bone is proceeding. A number of methods have been employed, of which the following are the most useful:—

(*a*) **Compression of the vessels by a figure-of-eight elastic tourniquet.** For the proper application of this method an assistant should be told off specially to look after it, but if the surgeon be short-handed, it is possible to use it without the aid of an assistant. It is used as follows: a piece of india-rubber tubing, the same thickness as that used for the horizontal elastic band in Esmarch's tourniquet and about four feet long, is put firmly on the stretch and its centre applied over the tendon of the adductor longus just at the fold of the groin; thence it is carried forwards nearly parallel to Poupart's ligament and backwards across the great sacro-sciatic notch, the two limbs meeting and crossing immediately above the crest of the ilium about two inches outside the anterior superior spine. To make the compression of the vessels more certain a firm sterilized pad may be applied over the line of the common femoral in front and the gluteal behind (see Fig. 147). The ends of the tourniquet, which should be sterilized by boiling, are then twisted round one another and pulled forcibly upwards by the assistant whose duty it is to see that neither the anterior nor the posterior pad slips during the operation, and to increase the tension on the tourniquet if necessary. If no assistant be available a large pad should be placed across the crest of the ilium, and the two limbs of the tourniquet made to cross over it, and the ends should then be carried horizontally round the trunk and tied together firmly over another large pad on the opposite side in the interval between the trochanter and the crest of the ilium. A tourniquet applied in this way controls the sources of bleeding front and back quite satisfactorily.

In all cases the limb should be elevated for five minutes before the

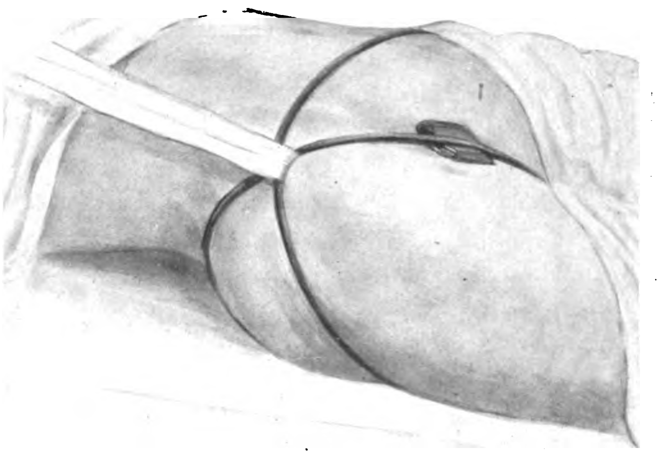

FIG. 147. INDIA-RUBBER TOURNIQUET APPLIED FOR DISARTICULATION AT THE HIP-JOINT. A pad is applied over the femoral artery and a loop of bandage is passed beneath the crossing of the cord in order to prevent its slipping; one limb of the loop should pass behind the thorax, the other in front of it.

tourniquet is applied, in order to empty it of blood; after the tourniquet has been put on, the amount of compression may be gauged by feeling for the pulse in the arteries of the foot. If there be no assistant to whom the management of the tourniquet can be specially delegated, or if the patient be fat and there be a risk of its slipping, a simple way of keeping it in place is to take a long loop of bandage, pass it beneath the tourniquet, and to carry the two ends, one behind the back and the other across the chest, and to tie them together over the opposite shoulder so as to form a loop or sling which prevents the tourniquet from becoming displaced. Another way to prevent displacement when an assistant is available is to apply the tourniquet in the figure-of-eight already described, and then to pass sterilized strips of bandage beneath the tourniquet over the femoral and gluteal vessels, which the assistant can pull upon and so prevent the tourniquet from slipping down. There is a constant tendency for the rubber bandage to slip during the latter part of the operation, as the disarticulation tends to displace it.

The chief drawbacks to this really excellent plan of controlling bleeding in these severe operations are three in number. Firstly, it requires an assistant specially told off to look after it. Secondly, there is the well-known persistent paralytic oozing after its removal; objectionable as this feature is in any operation, it becomes doubly dangerous at the hip when we remember the great size of the oozing surfaces. Thirdly, the rubber tubing is apt to perish unless it is kept in water and in the dark, and at the last moment the surgeon may be deceived by the tourniquet upon which he has been relying.

(*b*) **Compression of the abdominal aorta.** This is a simple and effective method in children. In adults, however, it can only be satisfactorily employed in very spare subjects, and is difficult in those who cough or strain under the anæsthetic. It may be effected according to either Macewen's or Lister's method. In the former the assistant stands on the left side of the patient on a level with the umbilicus with his back to the patient's head, and thrusts his closed fist down upon the aorta, so as to compress it against the spine just to the left of the middle line and immediately below the umbilicus. It is well for the assistant to stand upon a stool on his left foot so that he can exert any amount of pressure required with ease by simply leaning more of his weight on his right hand; he can easily gauge the pressure he is exerting by feeling for pulsation at Poupart's ligament. This method is applicable to adults.

Another very useful plan is Lister's method, which is most suitable for children or for very spare subjects. A piece of stout board, which should project nearly a foot beyond the trunk on each side, is passed beneath the back on a level with the umbilicus, a firm pad is placed over the aorta a little to the left of the middle line and just below the umbilicus, and stout india-rubber tubing is then stretched across the pad on the front of the patient's abdomen like the string of the bow from one end of the board to the other. Suitable notches or holes are cut in the ends of the board to secure the tubing.

Neither of these methods is likely to cause damage to the soft parts if the pressure be judiciously exerted. Both are therefore preferable to compression by any unyielding instrument such as Lister's abdominal tourniquet or digital compression reinforced by heavy weights.

(*c*) **Preliminary ligature of the common femoral artery.** When the incision for the disarticulation is begun in the immediate vicinity of Poupart's ligament attempts to control the vessel by pressure directly over it would be futile. The best plan, then, is to cut down upon the common femoral vessels at the commencement of the operation, divide them between ligatures, and push the ends well out of the way; the remaining steps of the operation can then be completed without fear of bleeding from these vessels or their branches. The only arteries likely to give rise to trouble will be the gluteal and sciatic, but it is easy to pick up these as they are divided if a watch be kept for them.

These are the chief methods of controlling the hæmorrhage, and one or other will generally suffice.

FURNEAUX JORDAN'S OPERATION

The following method will, on the whole, be found the best for performing this amputation. There are several ways of doing what is known as Furneaux Jordan's amputation; Mr. F. Jordan's original description will be found in his *Surgical Enquiries.*

Operation. The surgeon in each case stands on the outer side of the limb. After the figure-of-eight india-rubber tourniquet or some other suitable hæmostatic means has been applied, the patient is drawn right down the table, so that nearly the whole of the pelvis projects beyond its end, and is turned half over on to the opposite side. Care must be taken that the patient does not slip off the table during the various manipulations incident to the operation, and in order to prevent this it is a good plan to pass a sterilized roller towel round the perineum and secure it to the head of the table.

I have found it an excellent plan to elevate the lower end of the table in these cases until the patient is almost in the Trendelenburg position. This serves a double purpose; it prevents the patient from slipping off the table and also tends to minimize the loss of blood and mitigate the severity of the shock. If the operating table is adjustable in height it is lowered as much as possible so as to bring the pelvis on a level with the surgeon's elbows, but if not the surgeon will have to stand upon a stool of suitable height.

Every possible precaution must be taken against shock; the temperature of the operating theatre must not be less than 70° F., all bleeding vessels should be picked up as they are seen, and the steps of the operation should be performed as rapidly as possible. The question of making use of spinal analgesia (see p. 118) must be carefully considered in all these cases. There seems to be evidence accumulating to the effect that it lessens the shock in these very grave cases. It should certainly be used for traumatic cases.

The surgeon passes his arm beneath the affected limb and divides the skin as low down the thigh as he deems advisable by a circular sweep; if possible this should be at least eight inches below the top of the great trochanter. The first incision only goes through the skin and deep fascia, which are raised for about two inches by a few touches of the knife. The skin is then retracted as firmly as possible, and the muscles are divided down to the bone by a circular sweep of the knife, the femoral vessels being cut at the same time. The vessels are secured either in forceps or by ligatures before the remaining stages of the opera-

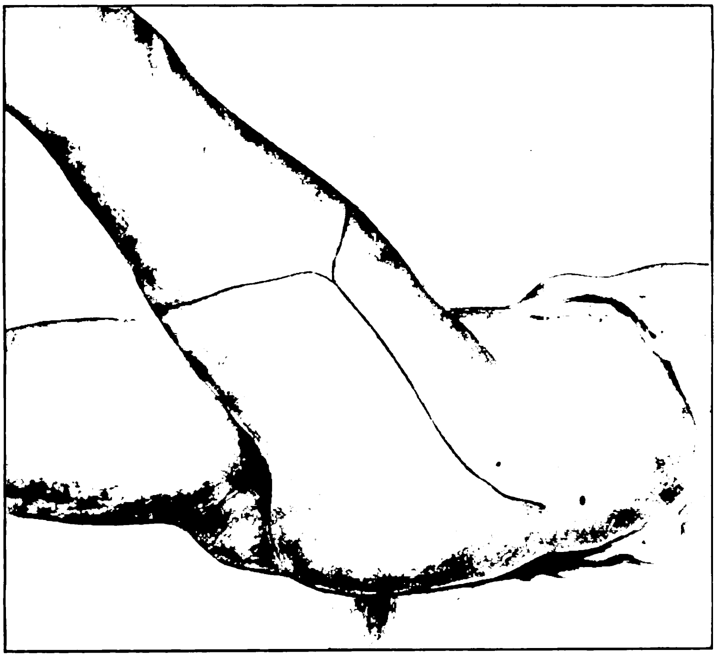

FIG. 148. INCISION FOR FURNEAUX JORDAN'S DISARTICULATION AT THE HIP. The two dots are placed respectively upon the level of the crest of the ilium and the top of the great trochanter.

tion are proceeded with; they are easily visible, and can be picked up without difficulty. When this has been done, a vertical incision (see Fig. 148) from the circular incision up to the mid-point between the great trochanter and the crest of the ilium is made over the outer surface of the femur, and the soft parts are rapidly stripped off the bone up to the level of the lesser trochanter. These stages of the operation may be done with the long knife which will be necessary for the circular division of the muscles. A few touches suffice for the separation, except behind, where the muscles arise from the linea aspera; the knife may be used freely here. The advantage of marking out the skin incision first is that this structure is allowed to retract to its full extent, and the incision through the muscles is made on a higher level than it would otherwise be; this enables the flaps to be brought together more neatly.

The amputating knife is now exchanged for a short-bladed stout scalpel, with which the remaining steps of the operation are performed. The best way to disarticulate is to have the limb abducted, rotated somewhat outwards and slightly depressed, when the psoas and iliacus can be divided at their insertion into the lesser trochanter, and the front of the neck of the femur and the capsule of the hip-joint are readily exposed. The latter is incised and the cotyloid ligament is divided by cutting firmly

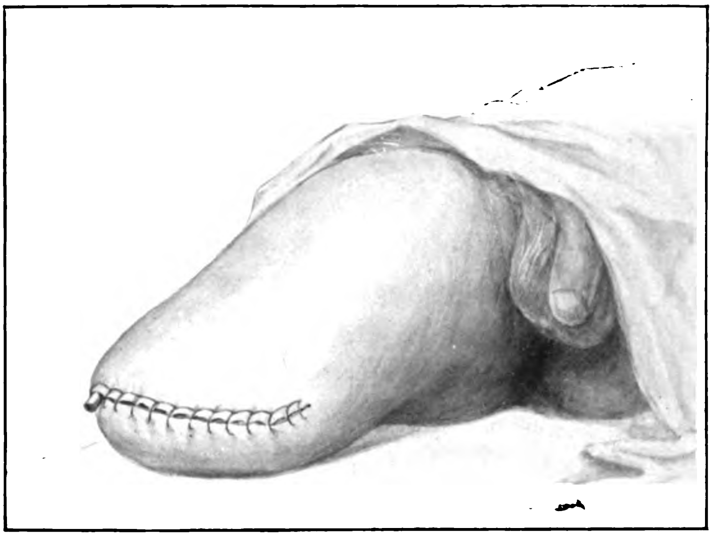

FIG. 149. STUMP LEFT AFTER FURNEAUX JORDAN'S AMPUTATION.

down to the bone with the point of the knife, the long axis of which is kept strictly parallel to the long axis of the neck of the femur (see Fig. 152). The assistant is now instructed to depress the limb still further and rotate it forcibly outwards, when the head of the bone comes out of the acetabulum, and the ligamentum teres can be divided. The head of the bone should be grasped in the left hand and the muscles attached to the great tuberosity divided by the knife passed behind it.

The raw surfaces of the large wound thus left are approximated as well as possible by deep sutures of stout silkworm-gut. One or two large drainage tubes are inserted according to the nature of the mischief for which the amputation is performed, and the edges of the flaps are brought together with continuous sutures (see Fig. 149). One large drainage tube at the lower end of the wound suffices for cases of growth or injury, but in a septic case a second large tube should be inserted at the upper end, passing horizontally to the region of the acetabulum.

There are certain special points in connexion with this operation which require mention.

When amputating on the right side the vertical limb of the incision is best made from above downwards, the point of the knife being sunk down to the bone midway between the top of the great trochanter and the crest of the ilium. Upon the left side, however, the vertical incision

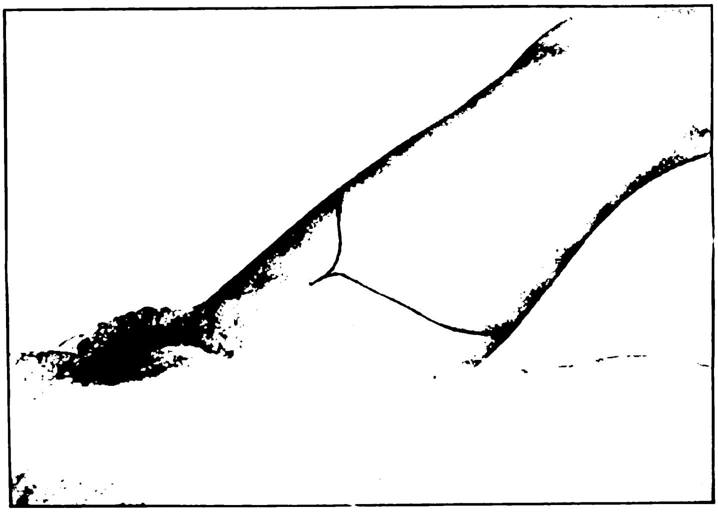

FIG. 150. IMPROVED METHOD OF MARKING OUT THE FLAPS IN FURNEAUX JORDAN'S AMPUTATION. This, taken in conjunction with Fig. 148, is the method of incision described in the text.

should be carried upwards from the circular amputation to the same point.

If the instructions for the amputation given above are followed out strictly, the resulting stump is a little clumsy, as the muscles tend to protrude through the edges of the skin and render suturing difficult. I find it preferable to modify the operation somewhat in order to obtain a more satisfactory stump. For instance, when operating upon the right side the arm is passed beneath the limb and an incision is made across the back of the thigh from the mid-point on the inner aspect of the limb to the corresponding point on the outer; this incision is boldly convex downwards and marks out a curved posterior flap, but it only goes through the skin and deep fascia. When the mid-point on the outer aspect of the thigh is reached, the incision is carried vertically up the limb and ends midway between the top of the great trochanter and the iliac crest. Then, by bending over the thigh, an anterior flap is marked out similar to the one behind and joining it at the commencement of the vertical incision along the outer surface of the thigh. This gives a better racket-shaped incision than the other (see Fig. 150), and a much neater stump results if these antero-posterior flaps, consisting of skin and subcutaneous tissues, be raised for the first two inches, and the muscles then divided by a circular sweep. When operating upon the left limb it is easier to cut the anterior flap first and then prolong this up into the vertical incision, and finally to cut the posterior flap. The remaining stages of the operation are similar to those already described (see p. 368).

In amputations done for a failed excision of the hip the operation is easier, as the head of the bone does not require to be disarticulated; this is the difficult part of the ordinary operation for the beginner. In these cases, however, the operation is often a very long one, as it is necessary to cut away all sinuses and foci of disease, and the acetabulum will require to be gouged out, while any intra-pelvic abscess must be opened up and drained. If there be extensive disease that cannot be got cleanly away, undiluted carbolic acid may be applied to the diseased surfaces and the wound left widely open and stuffed with iodoformed[1] gauze. It is useless merely to put in large drainage tubes and trust to the disease subsiding.

The difficulty of opening the capsule of the hip-joint and disarticulating rapidly is best got over by keeping the long axis of the knife parallel to that of the neck of the femur; this divides the cotyloid ligament transversely, and a slight depression of the limb will then cause the head of the bone to start out of its socket.

If the patient be obviously suffering seriously from shock during the operation, the final stages should be carried out in the Trendelenburg position, while at the same time an injection of two pints of normal saline solution should be given *per rectum;* if necessary this quantity or more may be administered subcutaneously or even intra-venously.

AMPUTATION BY LATERAL FLAPS—THE SO-CALLED ANTERIOR RACKET METHOD

This is an excellent amputation for cases in which the conditions do not allow of Furneaux Jordan's amputation being done; for example,

[1] By this term is understood cyanide gauze impregnated with sterilized iodoform. The iodoform is sterilized by prolonged submersion in 1 in 20 carbolic lotion and is then powdered freely over the moistened cyanide gauze.

cases in which there is extensive damage to the soft parts, or those of growth implicating the tissues of the thigh too high up to allow Furneaux Jordan's long flaps to be cut. The operation is accompanied by more shock than the preceding one, and special precautions must be taken to minimize this; it is well to do it under spinal analgesia in most cases, certainly in those where the operation is done for an injury.

The first stage of the operation is exposure of the common femoral vessels and their division between ligatures, the two ends being pushed aside out of the way of damage during the later stages of the operation; for the steps of this see p. 452. The patient is then brought down

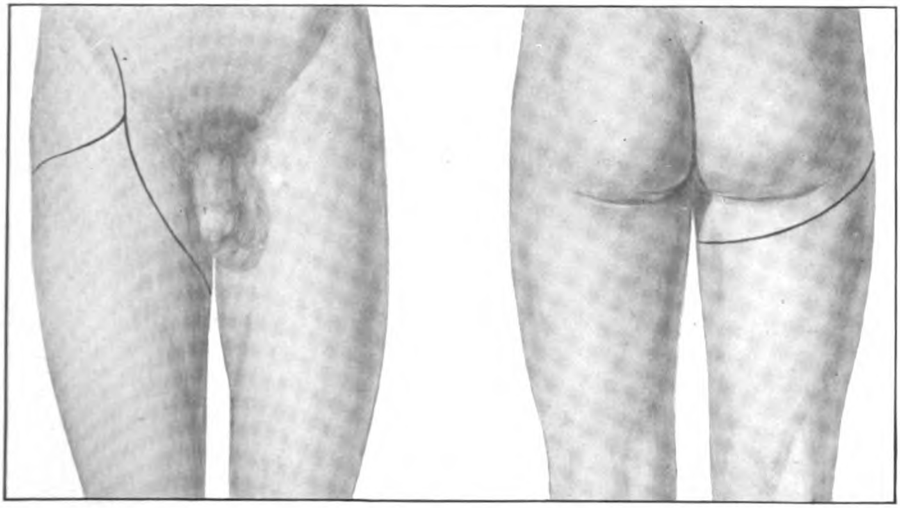

FIG. 151. INCISIONS FOR THE ANTERIOR RACKET DISARTICULATION AT THE HIP.

the table so that the buttocks project well beyond it, and the surgeon, standing on the patient's right of the limb to be operated upon, prolongs the incision for ligature of the femoral vertically downwards for a short distance and then carries the knife across the inner aspect of the thigh a good four inches below the fold of the groin, and makes it traverse the posterior surface of the thigh obliquely upwards and outwards until it reaches the outer aspect of the limb, across which it passes on a level with the base of the great trochanter to reach the vertical incision made for ligature of the common femoral about an inch below Poupart's ligament (see Fig. 151).

The incision is carried through the deep fascia all round so as to allow the skin to retract, and the surgeon then takes a shorter knife and divides the muscles. The sartorius, rectus, and tensor fasciæ femoris are divided in turn, and then the assistant flexes the thigh, rotates it inwards and adducts it, whilst the surgeon divides the insertion of the gluteus maximus. The limb is then adducted and rotated inwards still more forcibly,

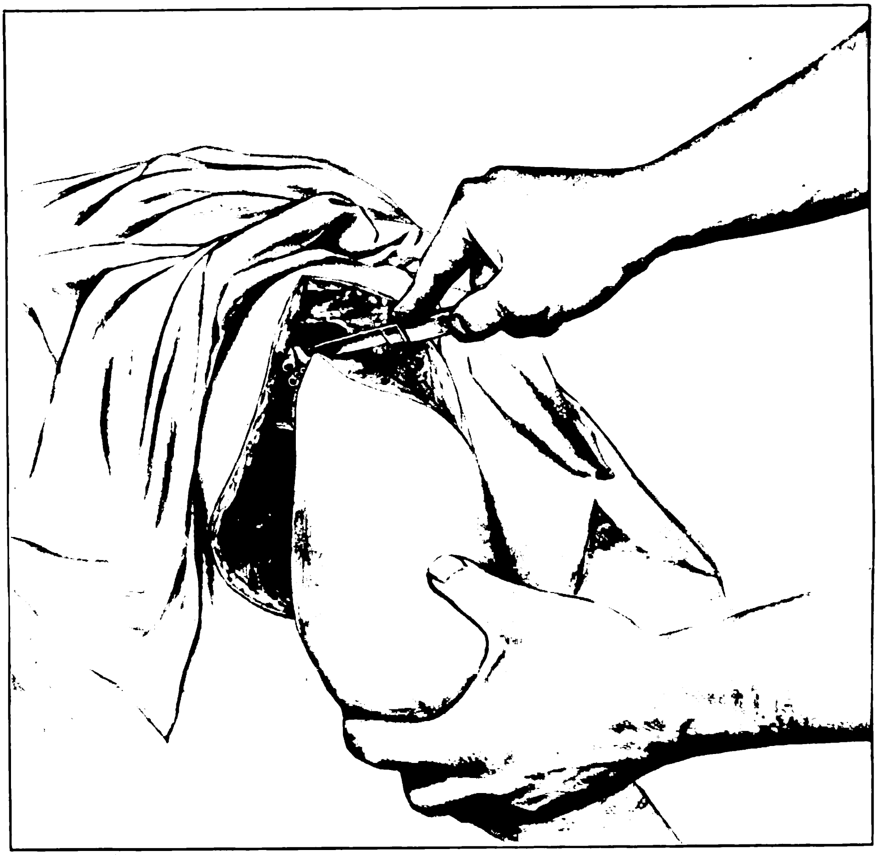

FIG. 152. DISARTICULATION AT THE HIP BY THE ANTERIOR RACKET METHOD. The knife is dividing the cotyloid ligament so as to allow the head of the bone to escape from the acetabulum. It will be noticed that its long axis is kept parallel with the neck of the femur.

the outer flap is pulled well up behind the great trochanter, and the knife is passed behind this process, dividing the muscles attached to it.

The muscles of the inner flap are next divided down to the bone, and the limb is abducted and rotated outwards, so as to expose the lesser trochanter, from which the ilio-psoas is detached. The assistant abducts the limb still more firmly and depresses it somewhat, whilst the surgeon divides the cotyloid ligament with the point of his knife, the long axis of which is kept parallel with the long axis of the neck of the bone (see Fig. 152). If the limb be depressed still further, the head of the bone will now start out of the joint, and the surgeon can seize it in his left hand, pass his knife behind it, and divide the capsule sufficiently to let it come well forward. He then takes a long knife, passes it behind the head of the bone, and divides from within outwards all the structures

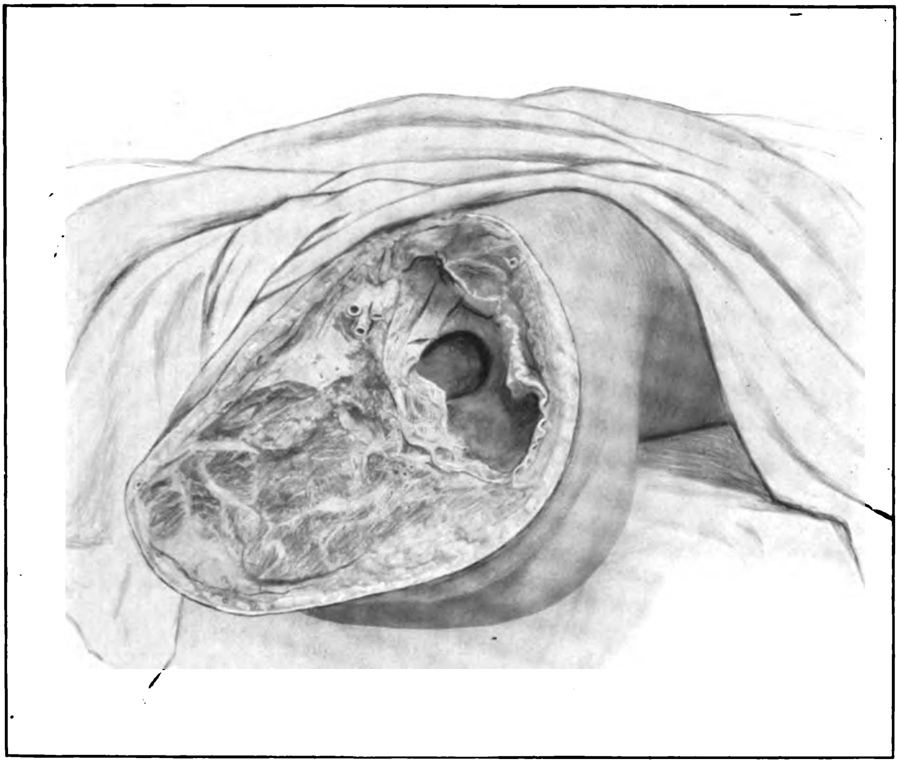

FIG. 153. FLAPS LEFT AFTER DISARTICULATION AT THE HIP BY THE ANTERIOR RACKET METHOD. It will be noticed that the flaps on the inner side are much longer than those on the outer, and the result when sewn up is shown in Fig. 154.

that have escaped division on the posterior surface. There will be some bleeding here from the branches of the gluteal and sciatic vessels, which must be arrested by picking up the vessels as they are divided.

When the flaps are brought together the cicatrix is well to the outer side and away from the genital region (see Fig. 154). A large drainage tube is inserted at the extreme outer end of the wound, and the flaps are kept together by deep sutures of stout silkworm-gut, reinforced by a continuous skin suture.

The only other disarticulation in this situation that requires mention is that by *transfixion;* in this operation the flaps are antero-posterior.

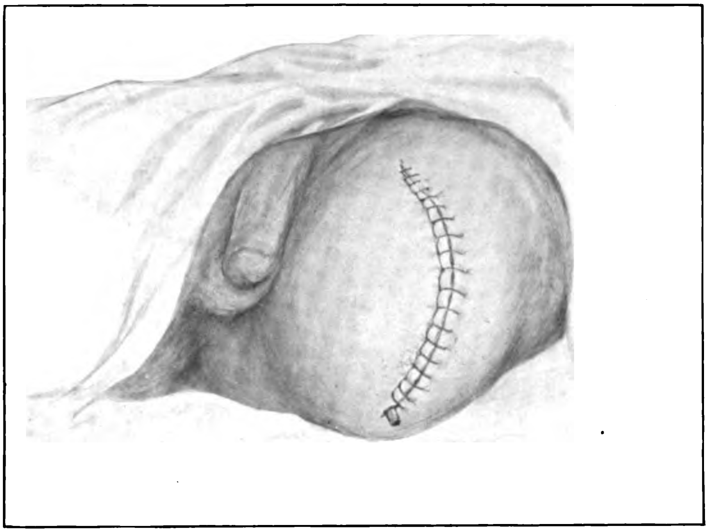

FIG. 154. STUMP AFTER DISARTICULATION AT THE HIP-JOINT BY THE ANTERIOR RACKET METHOD. The line of the cicatrix is well away from the genital region.

This method offers no advantage over the others save that of rapidity, and, as it has many disadvantages, such as bleeding and the increased risk of sepsis, it is not to be recommended and will not be described. It can only be called for upon the field of battle, and then, except in the hands of a surgeon who has practised it exclusively, would probably prove far more dangerous than either of the methods already described.

SECTION IV

OPERATIONS UPON ARTERIES, VEINS, AND LYMPHATICS

BY

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CHAPTER I

ARTERIORRHAPHY

THE work of Senn upon suture of blood-vessels first drew the attention of surgeons prominently to the fact that it might be possible to suture a wound in the wall of an artery with a good prospect of maintaining the circulation through the vessel unimpaired, and without giving rise subsequently to an aneurysmal dilatation of the vessel wall. The old view that a cicatrix in the wall of an artery must lead to the production of an aneurysm was therefore proved to be fallacious; the explanation of the frequency with which wounds of an artery are followed by aneurysm is probably to be found in the fact that when the edges of the wound are not brought together healing cannot occur.

Indications. It is obvious that arteriorrhaphy can be only rarely required, but under certain circumstances it would be most advantageous to be able to sew up a wound in the wall of an artery and thereby avoid the risk of gangrene which occlusion of a large artery may entail. The chief conditions under which operation may be called for are:—

(i) *Wounds of the large arterial trunks.* These are not very common, and will probably be accidental wounds occurring in the course of surgical operations, such as a wound of the common carotid in operations for removal of glands in the neck, wounds of the axillary artery in breast operations, &c. Occasionally it may be possible to suture punctured wounds of one of the big vessels when compression has been applied to the bleeding point in time to prevent the patient from dying before help can be obtained. Under these circumstances the operation should find one of its most valuable applications.

(ii) *For the removal of an embolus* blocking one of the large arterial trunks, in order to remove the clot, re-establish the circulation, and obviate the embolic gangrene that is otherwise sure to follow. This operation has been done more than once, but hitherto with very little success (Sampson Handley,[1] *Brit. Med. Journ.*, 1907, vol. ii, p. 702). The weak point in the procedure is that the embolus is usually infective and due to infective endocarditis, so that, even when the anatomical conditions allow of free access to and easy removal of the clot, the arterial

[1] Mr. Handley narrates an interesting case in which he attempted to unblock the femoral artery, which was filled with an embolus derived from the seat of an operation for strangulated hernia. In order to do this the aorta was compressed, and a stream of saline solution was injected through the profunda, which was cut across, by means of a ureteral catheter passed as high up as the aorta. Free bleed-

wall will have become infected and septic thrombosis will follow the removal of the embolus. It is, however, possible that, even when this is the case, the time gained might allow the collateral circulation to become established and the gangrene therefore averted, or its progress arrested.

(iii) If the recently introduced method of treating *incipient gangrene* from defective arterial supply by reversal of the circulation of the limb prove of practical service, arteriorrhaphy will become an important operation of surgery.

Various plans have been adopted for suturing incisions in arteries, and also for their end-to-end anastomosis after division. Of these the earliest methods were the through-and-through suture for closing wounds, taking up all the coats of the vessel on each side of the incision, and the invagination method of Murphy for end-to-end union; in this the proximal was invaginated into the distal end so as to get a firm joint, and the overlapping distal end was sewn to the wall of the invaginated part, taking up the two outer coats only. This method, however, is not only tedious and difficult to perform, but the rough divided end of the proximal invaginated portion projects into the lumen of the vessel, and allows fibrin ferment to escape into the circulation, with the result that thrombosis follows. It has been evident for some time that the earlier plan of introducing foreign bodies into the lumen of the artery for the purpose of supporting the suture is quite inadmissible, as coagulation is almost certain to follow.

As an improvement upon this method a suture was used in which the thread did not project into the blood-stream and so act as a foreign body promoting coagulation; it closely resembled Lembert's and penetrated only the outer and middle coats of the vessel, thus invaginating its walls somewhat. This method, however, was soon found to have two definite risks. The first was that the blood was apt to find its way between the coats of the artery and cause a dissecting aneurysm; the second was that the rough edge of the divided intima allowed the discharge of fibrin ferment into the circulation and promoted coagulation. The results were therefore generally poor. Dorrance, however (*Annals of Surgery*, 1906, vol. xlv, p. 409), improving upon the work of Carrel and others, has introduced a method of suture which is devoid of all the drawbacks above mentioned, and is the best with which the writer is acquainted. It is done as follows:—

ing from the profunda followed, but, as the superficial femoral remained blocked, the popliteal was opened, the common femoral compressed, and the superficial femoral washed out from the profunda. Unfortunately the patient's condition did not allow this part of the operation to be completed. Mr. Handley did not incise the artery directly, but this would be a quicker and probably a more effective method.

Operation. The vessel is exposed for a distance of an inch or more on each side of the wound in it, and is clamped with suitable artery clamps, such as Crile's (see Fig. 155), the blades of which are covered with rubber tubing. Only the right amount of pressure required to arrest the circulation should be exerted, and to ensure this the clamps should be screwed down until the bleeding from the wound in the vessel just stops. If Crile's clamps are not at hand a satisfactory substitute is a piece of sterilized tape about a quarter of an inch broad, which is passed under the vessel whilst the assistant places the pulp of his forefinger upon the upper surface of the artery and pulls the tape loop gently tight against it; this will arrest the circulation without damaging the arterial wall. Silk may be used instead of tape, but the latter exerts pressure over a wider area, and so is less liable to cause local damage to the arterial wall. It has been

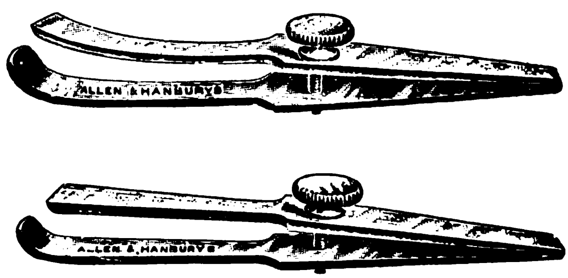


FIG. 155. CRILE'S ARTERY COMPRESSION CLAMPS. These are of two shapes, straight and curved, so as to facilitate application to different arteries; it is usual to sheath the limbs of the clamp with rubber tubing. The lower arm passes beneath the artery, the upper one acts as the compressor. The drawing is full size, and it will therefore be seen that the clamp does not get in the way; indeed, when it is employed for the temporary compression of the carotid artery for removal of growths in connexion with the buccal cavity, the entire instrument can be sewn up temporarily in the wound, which can then be covered with the dressing and is not liable to become infected.

amply proved by experiment that after a temporary compression of this kind exerted either by forceps or by ligature there are no permanent changes produced in the vessel wall.

When the circulation has been thus commanded, the wound is sutured with the finest spring-eyed round intestinal needle bearing the finest silk or celluloid thread obtainable. The method of suturing is very similar whether the operation be suture of an incision in the vessel or end-to-end union; it is explained in Figs. 156, 157.

When suturing a longitudinal incision the thread is first entered about an eighth of an inch from one end of the incision, made to penetrate only the outer and middle coats, brought out again and tied, the free end being left long. The needle is now made to penetrate all the coats of the vessel from without inwards on one side of the rent and as near the edge as possible; it is then carried through the walls of the vessel on the opposite side of the rent from within outwards. It then re-enters the arterial wall from without inwards, passes across the incision and penetrates the opposite side from within outwards, thus making a mattress stitch. This suture, however, is not tied in the usual way, but is

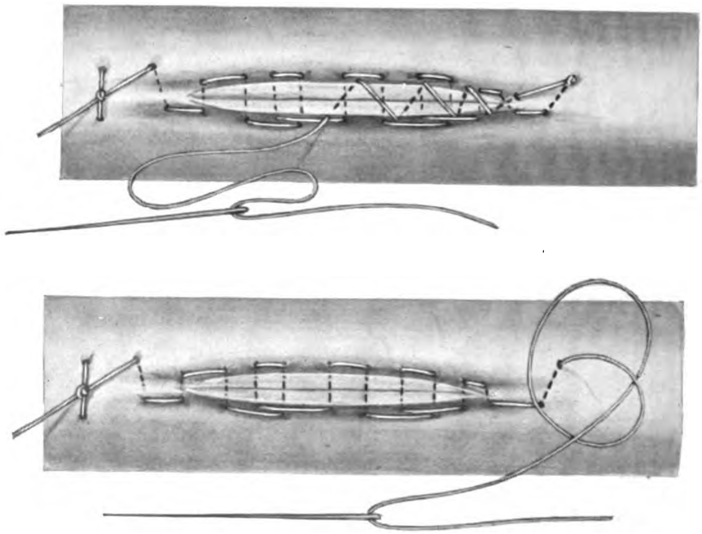


FIG. 156. DORRANCE'S ARTERY SUTURE. The suture is employed for the repair of a longitudinal wound of an artery. The lower figure shows the continuous mattress suture with the 'throw-back' in every third loop. It also shows the method of commencing and fastening off these sutures. The upper figure shows the suture continued from right to left to unite the superficial edges of the wound; when it is finished, its free end is fastened to the free end of the knot on the left-hand end.

continued as shown in the diagram throughout the length of the wound; at every third loop the suture is carried back a stitch's breadth, as shown in the diagram, in order to maintain the steadiness of the approximation. On emerging at the other end of the incision the thread is passed through the two outer coats of the vessel an eighth of an inch from the end of the incision, and is there tied in a single knot. The continuous mattress suture thus formed is reinforced by a second continuous running stitch taking up the edges of the incision between the loops of the mattress suture (see Fig. 156); when this reaches the point at which the original suture commenced, the two ends are tied together and the suture is complete. This method of suture approximates the intima on the two sides and at the same time buries the suture deeply so that it is out of the blood-stream, and there is neither any foreign body nor any cut vessel wall in contact with the blood-stream anywhere; the result is that little if any coagulation occurs at the seat of union.

After the suture has been completed, the clamps are removed, first from the distal and then from the proximal end, and, after having ascertained that the wound is blood-tight, it is a good plan to surround the

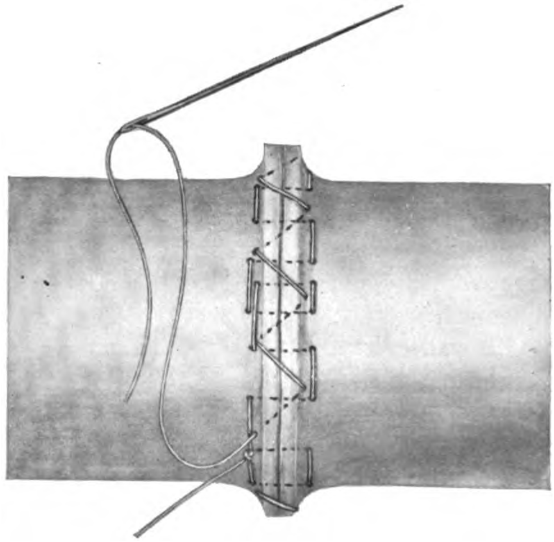


FIG. 157. END-TO-END UNION OF AN ARTERY BY DORRANCE'S SUTURE. The suture is similar to the one in the previous figure, and the diagram shows how the cut ends of the vessels are everted into a sort of flange.

artery by the deep fascia, which is sutured over it so as to make a loose cellular envelope.

When an end-to-end suture has to be made, it is done as shown in Fig. 157. The first suture is a mattress suture, the needle being passed through all the coats of the vessel from without inwards on the proximal side, and from within outwards on the distal side and back in the reverse direction. This gives a mattress suture with the ends projecting from the distal end; these are firmly fastened together so as to evert the ends of both segments. The remainder of the suture is completed by the continuous mattress stitch already described with the 'throw-back' at every third stitch. When this has completely encircled the vessel the end of the suture is fastened to the free end of the first mattress stitch. A continuous running stitch is carried all round, joining together the lips of the wound outside the suture as for a simple incision (see p. 379).

CHAPTER II

ENDO-ANEURYSMORRHAPHY

THIS term is used to designate an operation described by Dr. Rudolph Matas of New Orleans in a paper entitled 'An Operation for the Radical Cure of Aneurysm based upon Arteriorrhaphy' (*Annals of Surgery*, 1903, vol. xxxvii, p. 161), which has opened up a wide field for speculation and has created much enthusiasm, especially among American surgeons. Matas's operation is founded upon the two following assumptions:—

(i) That arterial suture or arteriorrhaphy is now a procedure of proved value, inasmuch as it is capable of securing permanent union between the opposed walls of the vessel.

(ii) That the intima of an artery is always prolonged from the lumen of the vessel for a certain distance at least along the wall of the aneurysmal sac, and that it is through the medium of changes occurring in the intima that union occurs when the two layers are brought into apposition by suture.

The object of the operation is to effect the radical cure of an aneurysm without any of the drawbacks inseparable from the older methods. Up to the date of publication of Matas's paper a radical cure could only be obtained by ligaturing the artery on both sides of the sac quite close to the latter, and then either extirpating the sac completely or leaving it *in situ* after incising it freely, evacuating all the clot and providing proper drainage. Under certain circumstances extirpation of the sac of an aneurysm is often hazardous and sometimes impossible without doing serious damage to important surrounding structures, whilst simple incision and drainage of the sac may lead to tedious healing or septic infection.

In certain suitable cases, moreover, Matas's operation aims at doing more than effecting a radical cure of the aneurysm. As will be seen later, it may be possible to reconstitute the lumen of the parent artery, and thus cure the aneurysm while maintaining the circulation unimpaired. This may be of the highest practical importance in certain cases which are referred to later.

Indications. By its author this operation is said to be 'applicable to all aneurysms in which there is a distinct sac and in which the cardiac end of the main artery can be provisionally controlled'. While this statement is no doubt correct, it does not, however, follow that one would be well advised to resort to its performance for the radical cure of every aneurysm that fulfils these conditions. For example, it would certainly be an unnecessarily laborious mode of treating small aneurysms of the extremities below the knee or the elbow; in cases such as these the size and situation of the parent vessels render it more convenient to apply a ligature above and below the aneurysmal sac and to excise the latter completely.

When dealing with aneurysms of the larger arteries, and particularly those situated in the groin, the axilla, the popliteal space, or the bend of the elbow, however, the position is different, and here Matas's operation is likely to prove a real advance in surgery. It may be taken for granted that, as long as the collateral circulation is not interfered with unduly, the ideal method of treating aneurysms wherever situated is to excise the sac completely, if possible, and, if not, to turn out all the clot and to secure rapid healing after having cut off the aneurysm from the circulation. In the situations just mentioned Matas's operation offers a better chance of attaining this ideal than does an attempt to apply a ligature on each side of the sac followed by partial or complete extirpation of the latter, for the anatomical condition of affairs in the axilla, the popliteal space, and the bend of the elbow is such as to preclude all idea of an extensive operation of this kind being done with any approach to safety. Matas's operation, on the other hand, does not disturb any important parts, while it effects a complete obliteration of the aneurysm.

It is, however, in connexion with the treatment of aneurysm of the aorta and its main branches that this operation bids fair to be of the greatest importance in the immediate future, should experience show that the good results of arterial suture obtained up to now prove to be permanent. Provided that compression can be applied on both sides of the aneurysm in these cases, there seems to be reason to think that the method may successfully effect a radical cure in these grave and important cases either by causing obliteration of the vessel as it enters and leaves the aneurysmal sac, or even by reconstituting the lumen of the artery, so that the great danger of gangrene from want of collateral circulation may be overcome. Even in the case of the aorta itself this method seems to offer a better chance of success than the application of a ligature.

A consideration of the comparatively few published cases leads to the conclusion that Matas's operation is most suited for the following cases:—

(i) Aneurysms of the extremities in which it is difficult to extirpate the sac wall after securing the vessel on each side of the sac. The chief of these are aneurysms in the groin, popliteal space, axilla, and bend of the elbow.

(ii) Aneurysms of the aorta or its main branches in which compression can be effectually employed on both sides of the aneurysm; effectual compression is a *sine qua non* and may be impossible here (*vide infra*). This question is discussed more fully in connexion with ligature of the abdominal aorta (see p. 469).

The 'restorative' operation of Matas is useless for a fusiform aneurysm; if any plastic operation could be done for an ordinary fusiform case it would be a resection of the diseased artery followed by end-to-end anastomosis or some plastic operation with a portion of a vein as an intermediate connexion. This will scarcely ever be advisable, however, even if it be possible (see p. 469). 'Reconstructive' operations are of use in fusiform aneurysms where the lumen of the artery is very large (*vide infra*) and sufficient healthy arterial wall is present to allow it to be brought together to form a fresh lumen.

Matas's operation is not always the best method of treating cases of arterio-venous aneurysm or traumatic diffuse hæmatoma; for these, simple arteriorrhaphy (see p. 379) suffices if the vessel be of sufficient size to make the operation worth while. In small vessels a ligature above and below the opening in the artery will be the best method of treatment. In bad cases, however, it may be found simpler to incise the vein, suture the orifice as in endo-aneurysmorrhaphy, and then suture the opening in the vein.

Operation. What is usually called 'Matas's operation' really embraces two distinct operations. In the one the object is to obliterate the lumen of the main artery altogether, whilst in the other an attempt is made to maintain the circulation through the main vessel unimpaired after effecting a radical cure of the aneurysm. These variations of the operation may be called the 'obliterative' and the 'restorative' methods respectively, and their applicability to any given case is governed by the pathological conditions present. Thus, except in certain cases referred to later (see p. 391), there is no chance of restoring the lumen of the vessel when its whole circumference is involved in a fusiform aneurysm; here the obliterative method must be employed. In a sacculated aneurysm, however, the orifice of communication between the artery and the sac involves only a small part of the vessel wall and there is an opportunity not only of curing the aneurysm, but also of reconstructing the artery afterwards; in other words, of employing the restorative method.

The first step in the operation is to control the circulation through the aneurysm effectually; unless this be done the operation is one of great difficulty and danger, although a case has been recorded by Abbé [1] in which a gluteal aneurysm was treated in this manner without effective compression of the parent artery. For a popliteal aneurysm or one at the bend of the elbow an Esmarch bandage is the simplest and most effectual method, as it cuts off the blood-supply from both sides, and, moreover, there is no bleeding from the sac even if vessels are given off from its wall, as is often the case in popliteal aneurysm. When the aneurysm is in the axilla or the groin it will be necessary to expose the main vessel well above and below it and to compress it with a temporary ligature (see p. 191) or with Crile's clamp (see Fig. 155). The latter is perhaps the most useful method of effecting temporary compression of the main artery alone, as it is easy to apply and its pressure is uniform, whereas a temporary ligature held by an assistant may be either too tight or too loose. The blades of the forceps should be sheathed with rubber, and when they are in position they should be screwed down very slowly until the pulse in the vessel below disappears. For an aneurysm of the aorta or the iliac vessels it would be necessary to have the vessel digitally compressed on both sides of the aneurysm, after having secured thorough exposure.

Dr. Matas, in a most interesting personal communication with which he has courteously furnished me since the above lines were written, lays special stress upon this question of 'effectual' control of the circulation. I cannot do better than quote the actual words of one who is not only personally familiar with the operative details to such an exceptional extent, but who is also *au courant* with what has been done in this line throughout the surgical world. He says:

'The problem increases in complexity and difficulty as the aneurisms to be attacked approach the root of the limbs, the neck, or regions where constriction is impracticable. This preliminary control of the circulation by obtaining a mastery of the great regional trunks in order not only to control the direct circulation in the aneurism, but that which is supplied by the collateral vessels, still remains, in the treatment of aneurisms by the intrasaccular methods, as good and thorough a test of the training and resources of a surgeon as it ever was in the days of the ligature and of extirpation. To illustrate what is meant I need only consider the difficulties in completely

[1] Abbé (*Annals of Surgery*, vol. xlviii, 1908, p. 10) records a case of aneurysm of the gluteal artery treated by Matas's method of continuous obliterative suture. He states that he attempted to control the circulation in the artery by employing a temporary silk ligature on the external iliac. On cutting into the aneurysm, however, he found that it bled freely, which is not surprising if it be correctly reported that he put the ligature round the external and not the common or internal iliac vessel; there is, however, probably a mistake in the report. The finger plugged the orifice of communication with the sac while the suture was carried out.

controlling the circulation in high femoral, ilio-femoral, and iliac aneurisms in which the opening of the sac may be followed by the most formidable and even fatal hæmorrhage if the inexperienced operator has trusted to the compression or temporary ligation of the parent artery immediately above and below the sac. The difficulty lies in the fact that numerous and large collateral branches open into the parent trunk at its junction with the sac, or empty into the sac itself in the intermediary space between the inlet and the outlet of the aneurism. In femoral, ilio-femoral, and iliac aneurisms of large size and of the fusiform type, the control of the parent trunk immediately above and below the sac is of no avail; the great vessel commanding the entire collateral supply of the limb must be compressed. In these cases it is only by compression and control of the common iliac through an abdominal incision that the collateral hæmorrhage from the obturator, sciatic, pudic, and gluteals can be controlled.

'In a very recent case of ilio-femoral aneurism even the compression of the common iliac and of the abdominal aorta at the bifurcation was not sufficient to secure an absolutely dry field. On opening the sac which had apparently collapsed, blood spurted out in a considerable stream, which was found to come from a well-developed epigastric which could not be controlled by the direct compression of the common iliac or of the abdominal aorta. It was only by direct pressure on the bleeding orifice in the sac and its direct occlusion with a clamp that the bleeding was arrested and that the technic was carried out to completion with deliberation. However, the temporary compression of the common iliac which controls all the branches of collateral importance given by its internal or hypogastric branches is sufficient, as a rule, to secure a safe, if not an absolutely ischemic field in the majority of cases.

'In the upper extremity, the hemostatic problem increases in gravity as we approach the axilla and the subclavian areas. In axillary aneurisms the third subclavian should be controlled, while an elastic bandage applied to the arm as near as possible to the lower pole of the sac prevents the lower collaterals from feeding the aneurism after it is opened. The circulation in the right subclavian should be controlled by a preliminary compression of the innominate, and on the left side by the first division of the subclavian.'

The sac of the aneurysm should be exposed with the least possible amount of dissection; generally a vertical incision in the line of the artery will be employed. It is essential that the soft parts should not be separated from the sac, and only important anatomical structures should be avoided as the sac is exposed. The latter is then incised from end to end in the long axis of the tumour. The clot is turned out and the cut edges of the sac are fully retracted so as to get a good view of the interior of the aneurysm. The surgeon notes the number of openings into the sac, whether there be a single one, as in the case of a sacculated aneurysm, or two, as in a fusiform aneurysm, or more, as will be the case when branches are given off from the part of the artery involved in the sac.

In a fusiform aneurysm two circular orifices are seen, one above and one below, connected together by a shallow vertical groove. In the sacculated aneurysm the orifice of connexion is usually ovoid. The number of orifices usually decides the nature of the operation to be performed; for fusiform aneurysms the obliterative methods, and for sacculated aneurysms the restorative, are the operations of choice.

(*a*) **The obliterative suture.** Any laminated clot adhering to the intima is rubbed away with a piece of sponge or gauze from the neighbourhood of the orifices of communication between the sac and the

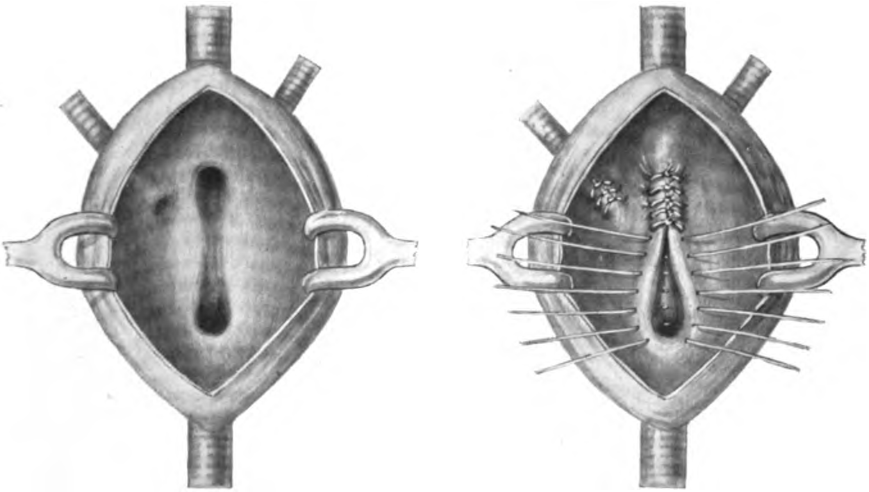


FIG. 158. THE OBLITERATIVE SUTURE IN ENDO-ANEURYSMORRHAPHY. (*After Matas.*) The figure shows the method of passing the sutures, which are here represented as interrupted ones. A branch coming off from the aneurysmal sac is shown secured in a similar manner.

vessel. Each orifice is then closed by a series of sutures inserted as shown in Fig. 158. These sutures may be of any material, but on the whole chromicized catgut is the best, as it holds firmly and long enough for union to occur, while it is eventually absorbed. The suture should be threaded in a fully curved, spring-eyed, round intestinal needle (see Fig. 159), and should be as stout as the needle will carry, so that it fills the hole in the tissues made by the penetration of the needle. Both needle and suture will vary with the size of the artery to be sutured, but the walls of the vessel are generally tough and the surgeon therefore may use a comparatively large size. The needle will need to be introduced by means of a needle-holder. Either interrupted or continuous sutures may be employed; perhaps a continuous running suture is the best. Each suture should be about one-eighth of an inch from its predecessor and should take a firm hold upon the tissues. It should be inserted through the inner wall of the sac about a quarter to a sixth of an inch from the edge of the communication with the artery, and should then pick up the

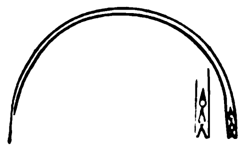


FIG. 159. SPRING-EYED NEEDLES. These are most useful in Matas's operation. They are easily threaded by springing the catgut into the eye, and, by being round and not triangular, they do not tend to enlarge the opening in the tissues as they pass through. The spring eye is most useful, as it enables them to be easily threaded with a suture that would only pass with difficulty through an eye of the ordinary shape.

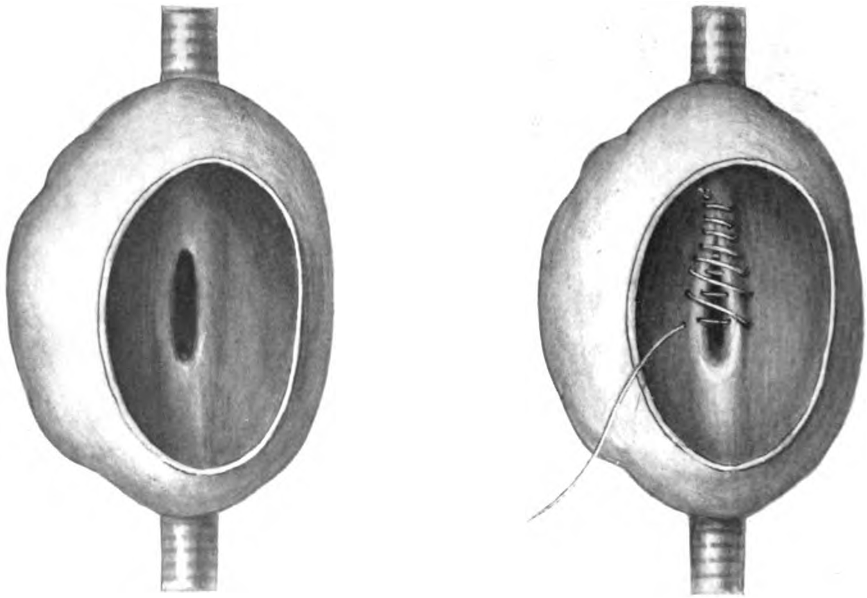


FIG. 160. THE RESTORATIVE SUTURE IN ENDO-ANEURYSMORRHAPHY. (*After Matas.*) In the left-hand figure the orifice of connexion between the artery and the aneurysmal sac is seen. In the right-hand one this orifice is closed by a continuous suture in the manner recommended by Matas.

floor of the latter as it enters the sac; it is finally passed through the opposite margin of the aperture of communication (see Fig. 158). Enough sutures are introduced to occlude the opening completely. The sulcus formed in the floor of the aneurysmal sac by the remains of the arterial wall stretching between the two orifices of communication may be quilted up by running the suture along it from one opening to the other if desired. This, however, is not necessary; it suffices to suture separately the orifices of communication with the sac. The orifice of any branch given off from the aneurysmal sac should be sutured in a similar manner. Matas advises a second layer of sutures in order to bury the first; this, no doubt, makes a stronger union, but is not absolutely necessary. The later stages of the operation are common to the two methods (*vide infra*).

(*b*) **The restorative suture.** In a case suitable for this method the aperture of communication between the aneurysm and the artery is single,

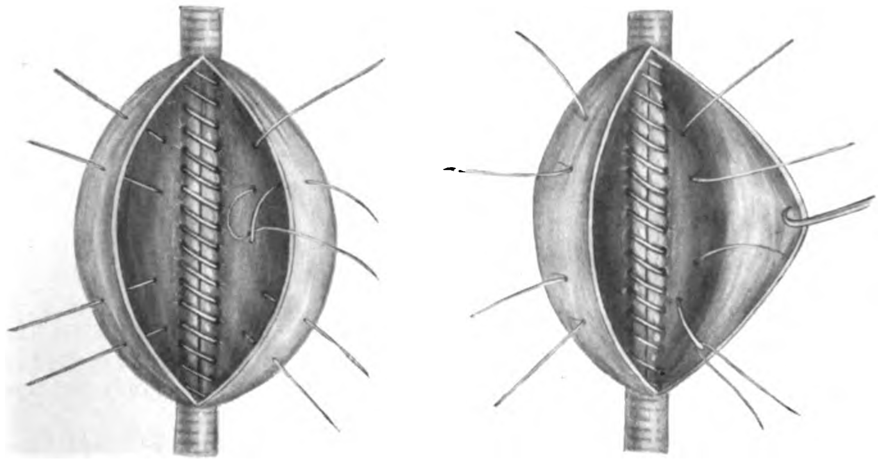


FIG. 161. OBLITERATION OF THE WALL OF THE SAC IN ENDO-ANEURYSMORRHAPHY. (*After Matas.*) The obliterative suture has been employed and the second suture layer, consisting of a continuous running stitch, has been applied as recommended by Matas. The various stages of introducing the sutures by which the superficial wall of the aneurysm is brought into close contact with the deep wall are shown. These sutures penetrate the skin over the superficial sac wall, as is shown in the following figure.

and the object of the suture is to approximate its edges so as to cut off communication between the aneurysm and the artery without obliterating the lumen of the latter. Similar needles and sutures are used, and the needle is entered well outside the edge of the aperture, but is brought out through its margin on the opposite side and brought out some distance from the edge. This gives a firm hold and does not diminish the lumen of the vessel. A continuous suture is best. A second layer of sutures external to this may be used in order to secure still firmer apposition; this suture of course takes up the sac wall only. It will be seen that in this method the suture must lie in the blood-stream unless the approximation be carried out with great nicety. Therefore the risk of thrombosis after the operation should be considerable.

Obliteration of the sac. The final stages of the operation are similar in both cases. When the suture has been completed, the pressure on the artery is relaxed in order to see if the suture be blood-tight; if it be found to leak, the pressure is reapplied and more sutures are inserted. The most important part of this stage of the operation is the obliteration

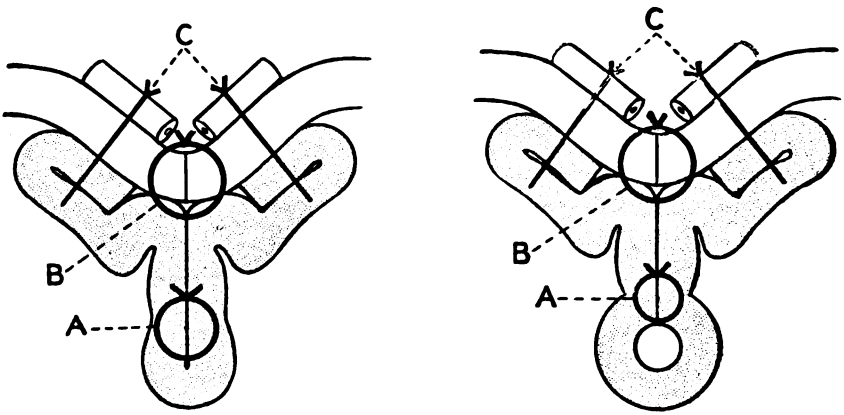


FIG. 162. DIAGRAM ILLUSTRATING A TRANSVERSE SECTION THROUGH AN ANEURYSM OBLITERATED BY MATAS'S METHOD. (*After Matas.*) In the left-hand figure the obliterative suture has been employed, whilst in the right the restorative form has been adopted. In both cases, in order to avoid confusion, only one layer of sutures in this region has been depicted.

A is the suture shutting off connexion with the artery; in the left-hand figure this is the obliterative, in the right the restorative form.

B is the suture fastening the skin to the wall of the sac in the middle line, while C are the sutures coapting the superficial and deep walls of the aneurysmal sac passing through the skin and tied over a roll of gauze or piece of india-rubber tube.

of the sac. Matas folds the walls of the sac upon themselves, and thereby avoids leaving a cavity which would require drainage. The sac walls are approximated by stout catgut or silkworm-gut sutures which take up the deep wall of the sac and are then passed through the superficial wall of the sac and the skin over it together and are tied over a pad of dressing; Figs. 161 and 162 show how this is done. It may be possible to clip away the superficial portions of the sac wall, leaving only the deeper parts to be brought into contact with the skin, which is sutured down to them.

Matas suggests in his paper (*loc. cit.*) that in large fusiform aneurysms, when the wall of the vessel is not too much diseased, it may be possible to perform a 'reconstructive' operation instead of the obliterative one. This can only be done in the case of a very large vessel, such as the common femoral or the iliacs, and Matas proposes to do it by suturing the walls of the vessel over a piece of drainage-tube of suitable size, which acts as a splint or mould for the newly-constructed lumen and which is pulled out after all but the last two or three sutures have been inserted and tied over it (see Fig. 163). It will thus be seen that there are really three distinct operations: (i) the obliterative, (ii) the restorative, and (iii) the reconstructive. The last two differ in the fact that whereas in the former the lumen of the artery is intact but for the orifice of com-

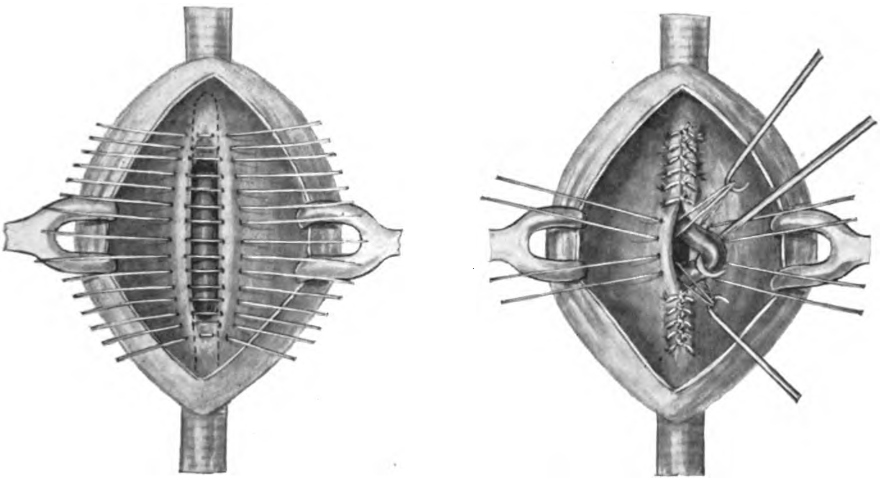


FIG. 163. THE RECONSTRUCTIVE METHOD AS APPLIED TO LARGE ARTERIES. (*After Matas.*) The figure shows a piece of rubber tubing laid into the lumen of the parent artery and the walls of the aneurysmal sac brought together by interrupted sutures over it so as to reconstruct the lumen of the artery. The right-hand figure shows the tube being hooked out after the majority of the sutures have been tied over it but before the last four are fastened.

munication, in the latter the lumen has to be almost entirely reconstructed out of the wall of the sac. This last operation is probably more valuable theoretically than practically; it would probably only be suitable for aneurysm of the abdominal aorta or the upper part of the common iliac, as it is almost certain to be followed by thrombosis, and it is hardly worth while to take the trouble of doing what is a very difficult operation except for cases such as those mentioned in which it is of great importance to stave off thrombosis, even though it be only for a short time, in order to allow the collateral circulation to establish itself to some extent.

Results. In this connexion it may be well to quote from an abstract of a paper read before the Surgical Section of the American Medical Association on June 3, 1908, by Dr. Matas, which I owe to his kindness.

Matas has reported in the 17th International Congress of Medicine in the section of surgery in 1913 the results obtained by his operation as follows:

Up to July 1, 1913, 225 cases had been operated by various surgeons, including Matas. The arteries involved in the aneurysms are distributed anatomically as follows: lower extremity, 194; upper extremity, 23; neck, 4; abdominal aorta, 4. In the lower extremity are included the posterior tibial, 2; popliteal, 130; femoral, 44; iliofemoral or inguinal, 10; external iliac, 5; gluteal, 3.

The popliteal group shows up, as in all statistics, as the largest subdivision, not only in the lower extremity, of which 67% were popliteal, but of the entire collection, comprising 57.8% of the whole, the femoral group following with 19.6%. It is evident, therefore, that of all the peripheral arteries the popliteal is by far the most frequent seat of aneurysm.

In the upper extremity there were 23 cases. Of these 7 involve the subclavian, 3 the axillary, 12 the brachial, 1 the ulnar. Of this group the largest number as usual is represented by the brachial, 52.1% (or 5.3% of the total 225).

In the neck there were 4 carotid aneurysms and in the abdominal aorta 4.

Up to June, 1908, there were in 85 cases over 58% popliteal and over 21% femoral.

The endo-aneurysmorrhaphies performed upon these aneurysms were classed into 3 groups:

The obliterative operation	150 cases or 66.7%
The restorative group	50 cases or 22.2%
The reconstructive group . . .	25 cases or 11.1%

The restoratives and reconstructives combined equalled 75 cases or 33.3% of the entire collection. This simply shows that the operators found it advantageous to avail themselves of the favourable conditions found in the sac to attempt the preservation of the lumen of the parent artery in one out of every three cases. This does not mean that in only one-third of the cases were the conditions such as to permit the restorative and reconstructive methods, but simply that these procedures were adopted in that number of cases, because there are many operators who have had a large experience with the intrasaccular suture (Bullock, Gibbon and Dana, etc.) and who are so well satisfied with the results of the obliterative method that they do not attempt the reconstructive or restorative method, even when the conditions in the sac are favourable to these procedures.

In a general summary of 225 cases we find that there were 19 deaths (8.4%), including 4 fatal aortic aneurysms; 206 recoveries or 91.6%; total operative failures, 20 or 8.8%; total successes or cures 205, or

91.2%; total gangrenes 11 or 4.8%; total relapses 3 or 1.33%; secondary hæmorrhages 3 or 1.33%.

If the 4 fatal aortic aneurysms are eliminated, the total is reduced to 221 cases and the gross mortality is lowered to 15 deaths, or 6.7%. The recoveries are 206 or 93.2%; the operative successes or cures 205 or 92.8; the failures 16 or 7.2; gangrenes 11 or 4.9%; relapses 3 or 1.35%; secondary hæmorrhages, 3 or 1.35%.

ANALYSIS OF DEATHS

Of these 19 deaths, the following should be eliminated as not attributable to the operation, but due to complications, accidental and associate conditions, which are common to all trauma, and for which this particular procedure cannot be made responsible.

Upper extremity. 1 (Ransohoff's case). Sudden death on the operating table at the close of an obliterative operation for a subclavio-axillary aneurysm. The death was attributed by the operator to an air embolism, for lack of other satisfactory explanation.

Lower extremity. The following seven cases should be eliminated.

1. Gibbon: sudden death on table at the close of an unusually simple obliterative operation for popliteal aneurysm. Death attributed to the anæsthetic. 1. Gibbon: from nephritis two months after recovery from an obliterative popliteal operation. 1. Stafford: from tetanus thirty days after obliterative operation for popliteal aneurysm. 1. Pantzer: complete healing of wound without defect in the line of suture and open from pyelonephritis on the 15th day. Post-mortem examination showed lumen of the artery. 1. Gessner: fulminating erysipelas, which occurred on the 18th day in a patient recovering from an obliterative operation for traumatic aneurysm of the profunda femoris. The wound had nearly healed when the erysipelas appeared, contracted from an infected ward. It assumed a malignant character from the start. 1. Souchon: death on 45th day from acute septic arthritis of the knee after patient had recovered from an obliterative operation for femoral aneurysm. Examination of the specimen, still preserved in the museum, shows aneurysmal sac completely obliterated and the entire limb in a perfect state of preservation, with a thoroughly developed collateral circulation. 1. Old: patient (man aged 55 years) died five hours after an obliterative operation for a spontaneous external iliac. Autopsy showed nothing abnormal about the site of the aneurysmal operation, but a thrombus was found in the pulmonary artery.

Neck. One of the two deaths should be eliminated, as it occurred suddenly and unexpectedly on the 8th day after an obliterative operation for arterio-venous aneurysm of the carotid vessels. The autopsy showed advanced coronary disease and no condition in the wound to account for death. The patient had been a hemiplegic in consequence of a cerebral embolism which occurred at the time the neck injury was inflicted, fifteen years before operation.

Summary. By eliminating these 9 cases from the total gross mortality and excluding the 4 aortic cases, the mortality is reduced to 6 in 221 or 2.7%.

There were 11 gangrenes, all in the lower extremity, requiring amputation and 7 of these recovered. The causes of death in the other 4 were: tetanus, 1; secondary hæmorrhage, 1; septic peritonitis, 1; and unknown, 1.

One minor gangrene involving parts of toes occurred. The patient recovered with preservation of toes and limb. If this is included in total gangrene, the percentage would be 12 in 225 or 5.3%.

It is to be noted that no gangrenes occurred in the upper extremity.

The end-results following the recovery of the patients after typical and successful intrasaccular operations are remarkably free from permanent secondary disabilities. In the entire collection only 5 cases have been reported in which some form of disability persisted after the patient had recovered from the operation. These disabilities refer to two popliteal cases in which œdema of the leg and foot persisted.

In two cases of popliteal aneurysms there were foot-drop and paræsthesia due to nerve compression and pressure neuritis before operation, and the other caused by accidental injury of the popliteal nerve.

CHAPTER III

OPERATIONS FOR ANEURYSMAL VARIX AND VARICOSE ANEURYSM

ANEURYSMAL VARIX

In connexion with the operative treatment of this affection, the possibilities that the work of Senn, Murphy, Matas, and others upon methods of suture of the arteries has opened up may be usefully borne in mind. While in the case of the smaller vessels there is no objection to removing the portions of the artery and vein concerned in the aneurysmal varix, this might possibly endanger the circulation in the limb when the affection occurs high up, as, for instance, in Scarpa's triangle. In these cases there seems reason to think that the best operation is to expose the seat of the varix by careful dissection, and, after the anatomy of the affection has been made out accurately, to clamp both vessels temporarily above and below the communication, which is then obliterated.

Operation. The simplest plan is to cut across the connexion between the artery and the vein and to suture the wound left in the artery and in the vein separately whenever this is possible. The opening in the vein should be closed by a lateral continuous suture applied as described on p. 527, while that in the artery is brought together by a continuous mattress suture similar to that shown on p. 380, which brings together the intima on each side of the incision and does not allow either the cut edge of the artery or the suture material to project into the blood stream. It would probably not be necessary to encroach upon the lumen of the artery to any extent, as the connexion between the artery and the vein would probably be sufficiently extensive to allow of the arterial walls being coapted without any considerable diminution of its calibre. As a rule, the dilatation of the vein present will allow the incision separating the two vessels to be made somewhat at the expense of the vein wall without running any risk of unduly narrowing the calibre of that vessel when it is sutured. This has the advantage that it will leave enough tissue outside the opening into the artery to bury the suture layer closing it.

It is not to be expected, however, that this method will be always applicable. The opening into the artery may be so placed or of such a size and shape that arteriorrhaphy will not be practicable without running a great risk of occluding the lumen of the vessel. Even in this case, however, there is no valid reason why the attempt should not be made, as the only alternative is to apply a ligature to the artery above and below the orifice of communication and thereby cut off the circulation. The common femoral artery is large enough to enable the necessary manipulations to be carried out, and even some narrowing of its lumen is presumably preferable to its complete occlusion. Should thrombosis occur subsequently at the seat of operation a certain amount of time may be gained in which the collateral circulation will have a chance of establishing itself.

The treatment of the communication in the veins will offer little difficulty. The vessel will be so large that the opening in it can be closed easily by suture without much risk of thrombosis occurring.

VARICOSE ANEURYSM

Operation. This will either take the form of a modified endo-aneurysmorrhaphy (Matas's operation) or the application of a ligature to the vessel above and below the sac, leaving the untouched aneurysm to empty out into the vein, the circulation through which will be unaffected.

On comparing the merits of the two operations the balance of advantage seems to lie with Matas's operation, since it ought to be able to secure not only a radical cure of the aneurysm but probably also a reconstitution of both artery and vein. Simple ligature of the main artery above and below the communication will not necessarily cure the condition. Should there be a branch coming off from the sac, this may escape notice at the time of operation and may cause the condition to persist and necessitate ligature of the vein above and below the communication at a later date. Matas's operation, however, has the advantage that by means of it any branches given off from the sac wall can be secured if present, and all danger of reflux through the aneurysm into the vein by means of collaterals between the ligatures on the parent vessel would be done away with. It is essential for its successful performance, however, that it shall be possible to control the circulation effectively on both sides of the aneurysm both in the artery and the vein, and therefore the modified Matas operation will not always be possible. For an interesting paper on this difficult subject see Bickham (*Annals of Surgery*, May, 1904).

The steps of the operation have been already described in full (see p. 384). In these cases it would be necessary to control the circulation through both artery and vein, and, at the end of the operation on the artery, to close the opening into the vein by similar sutures.

CHAPTER IV

BLOOD TRANSFUSION

PART I. BY N. M. PERCY, M.D., F.A.C.S.
PART II. BY RICHARD LEWISOHN, M.D., F.A.C.S.

PART I

INDIRECT TRANSFUSION OF UNTREATED BLOOD

By N. M. PERCY, M.D., F.A.C.S.

THE most important part of transfusion is the selection of a healthy donor and the making of hemolytic and agglutination tests between the two bloods. In addition to this, it is well to determine as nearly as possible the exact condition of the blood before transfusion in both donor and recipient. This examination should consist of a red and white cell count, hemoglobin per cent., coagulation time, a differential count, and a description of the various types of corpuscles.

Donor. In selecting a donor it is important, in addition to making hemolytic and agglutination tests, that a careful history be obtained from the donor, and a complete physical examination made, including a Wassermann test. Donors should not be chosen from persons giving a history of recent attacks of typhoid fever, pneumonia, diphtheria, tonsillitis, malaria, or influenza, nor from persons suffering from tuberculosis, chronic arthritis, rheumatism, or where there is a history of hæmophilia.

Hemolytic and agglutination tests. A hemolytic or agglutination test of each blood upon the other should always be made before transfusion, because it has been found that in a considerable per cent. of cases there is a tendency of the serum of one blood to cause a disintegration of the red cells of another, even when the latter be a near relative. While the bloods from members of the same family are more apt to be compatible with each other than aliens' blood, still it is never safe to use even a close relative as a donor without first making a hemolytic test between the bloods to be mixed.

Agglutination test. During the past two years the writer has been determining the hemolytic action of the blood by the Moss method,[1] the technique of which has been modified by Brem.[2] This method is based on the principle that before the serum of one blood will cause an hemolysis of the corpuscles of another, it will first, or simultaneously, cause an agglutination of the corpuscles. The reverse, that all cases that show agglutination will also show hemolysis, is not necessarily true, only occurring in about twenty per cent. of cases. Adopting this principle, all bloods are classified according to the agglutinative properties of their elements into one of four groups. In selecting a donor, it is always advisable to have a donor whose blood belongs to the same group as that of the patient. If this is impossible, the donor's blood should belong to a group whose corpuscles are not agglutinated by the serum of the patient. The bloods of group IV answer this requirement for all other groups, as its corpuscles are not agglutinated by the serum of any group. Fortunately group IV is the most common group, Moss having found that forty-three per cent. of all individuals belong to this group.

Moss found that all bloods, whether normal or pathological, could be classified into four groups by agglutination tests of the serums against the corpuscles. He found the groups to be as follows:

Group I. 10%—Serum does not agglutinate corpuscles of any group.
Corpuscles are agglutinated by serum of II, III, & IV.

Group II. 40%—Serum agglutinates corpuscles of groups I & III, not IV.
Corpuscles agglutinated by serum of III & IV, not I.

Group III. 7%—Serum agglutinates corpuscles of groups I & II, not IV.
Corpuscles agglutinated by serum of II & IV, not I.

Group IV. 43%—Serum agglutinates corpuscles of groups I, II & III.
Corpuscles are not agglutinated by any serum.

The serum of one group will not agglutinate the corpuscles of blood belonging to the same group.

Moss chart, showing the reaction of the various groups against each other.

In grouping, the unknown blood should be tested with a blood whose group is known. This 'standard' blood must belong to either group II or III in order to be of any value in grouping other bloods. The group to which a blood belongs becomes fixed by the third year of life, and remains constant. It is not influenced by age, disease, or transfusion of blood belonging to another group.

As shown in table it will be seen that the serums and corpuscles

[1] Moss: *Bull.* Johns Hopkins Hospital, March, 1910.
[2] Brem: *Jour. Am. Med. Assoc.*, July 15, 1916.

of the same groups do not in any way interact. It will also be noted that there is a wide, undetermining variety of reactions possible in the cases of group I and IV. The reactions in the two remaining groups are more limited and definite, and for that reason groups II or III only may be used as the standard in the Moss test.

CORPUSCLES

Group I	Group II	Group III	Group IV	Serum
o	o	o	o	Group I
+	o	+	o	Group II
+	+	o	o	Group III
+	+	+	o	Group IV

The basis of the blood examination for transfusion is the agglutination reaction. Agglutination is considered as an early stage of hemolysis and is always present, hemolysis never occurring without a primary agglutination of the blood cells, while, on the other hand, agglutination may occur, and does occur, without hemolysis. It is from this agglutination that we arrive at our conclusions. The serum of a given blood contains a protective agent (anti-hemolysin) for its own corpuscles, this serum having a tendency to prevent hemolysis. The serum does not contain a corresponding anti-agglutinin, so hemolysis may be prevented without in any way hindering the agglutination reaction. In the original method of Moss, two platinum loopfuls of the agglutinating serum were added to one loopful of corpuscles from the blood to be tested. By this method oftentimes the stage of agglutination was so transient that its presence was not recognized, and the agglutination went on to complete hemolysis. The correct interpretation of the test was therefore impossible, as the observer failed to recognize the determining factor, agglutination. To remedy this, Brem, besides the two loopfuls of agglutinating serum and one loopful of the corpuscles of the blood to be tested, added one loopful of the protecting serum; that is, serum of the same blood from whence the corpuscles were derived. This protective serum, as we stated above, contains anti-hemolysins, but not agglutinins. By this means the agglutination is not in any way affected, but the hemolysis of the blood cells is retarded or prevented, so giving a relatively slow, definite, easily recognizable stage of agglutination. The technique, based upon these considerations, is as follows:

Ten to 20 drops of blood are collected in a small test tube from the lobe of the ear. This is allowed to clot and then the tube is centrifuged so as to obtain a clear serum above. This is the protective serum when used with its own corpuscles, but when used with the corpuscles of another blood, it is called the agglutinating serum. In another small test tube are collected two drops of blood in about 1 c.c. of solution composed of 1.5 gm. sodium citrate, 0.9 gm. sodium chloride in 100 c.c. of distilled water. This gives approximately a five per cent. suspension of the corpuscles. This tube requires no further preparation.

Upon cell slides rimmed with petrolatum to prevent evaporation are made ordinary hanging drops.

On one slide are put:

2 loopfuls of standard serum (agglutinating serum) plus
1 loopful of the suspension of corpuscles of the blood to be tested, plus
1 loopful of the protecting serum; that is, the serum from the same blood as the corpuscles.

On the other slide:

2 loopfuls of the unknown serum (of the blood to be tested), plus
1 loopful of the suspension of corpuscles from the standard or known blood, plus
1 loopful of its protective serum.

It will be seen from the above table that one slide contains the standard or known serum, while the other, the standard or known corpuscles. Deductions are made, using the standard serum and corpuscles as a basis (group II or III used as the standard group) after the agglutination is recognized.

For instance, if using group II as a standard, we get agglutination in the slide containing the standard serum, and none in the slide containing the standard corpuscles, the undetermined blood is of group I. From the above table we will find that the serum of the standard blood (group II in this case) agglutinates the corpuscles of groups I and III, and not of groups II or IV, and that the corpuscles of this standard group II are agglutinated by the serums of groups III and IV, and not by groups I or II. Then, since there is agglutination in the slide containing the serum of the standard group II, the undetermined or unknown blood must be either of group I or III. In the other slide, containing the corpuscles of the standard group II, there is no agglutination, so the unknown blood must be either of group I or III. Since group I satisfies the agglutinating reaction in both instances, the unknown blood must belong to that group.

If agglutination occurred in both slides, prepared as stated above, by similar deductions we find that the undetermined blood would belong to group III, as the standard serum agglutinates the corpuscles of groups I and III, and not of groups II or IV, while the standard corpuscles are agglutinated by the serums of groups III and IV, and not by groups I or II. As the serum and corpuscles of group III satisfy the agglutinating reaction in both instances, the blood being tested belongs to that group.

Taking the third possible reaction, if no agglutination occurred in the slide containing the serum of the standard blood, and agglutination was present in the slide containing the standard corpuscles, the undetermined blood would be of group IV, since, from the table given above, we see that the standard blood (group II) agglutinates the corpuscles of groups I and III, and not of II or IV. The standard corpuscles of group II (the standard blood used in this instance) are agglutinated by the serums of groups III and IV, and not by I or II. Therefore, the serum and corpuscles of group IV satisfy the agglutinating reaction of group II, the standard. Consequently, the blood tested belongs to group IV.

Lastly, if there occurs no agglutination in either slide, the unknown blood is of the same group as the standard blood used, as bloods of the same group do not in any way interact.

These are the four possibilities in using group II as a standard. The method of deduction is identical to that given above when using group III as the standard.

An endeavour should always be made to have the donor and recipient of the same group, so reducing to a minimum the possibilities of reactions. If, in an emergency, blood must be given immediately, or if the recipient be a member of group I or III, the rarer groups, certain deviations may be practised in which bloods of unlike groups can be used. Under such conditions, the serum of the recipient must never agglutinate the corpuscles of the donor, while the serum of the latter may agglutinate the corpuscles of the patient. The serum of the donor, as it enters the blood stream of the recipient, is diluted to such an extent as to be practically inactive. The lack of agglutination of the patient's corpuscles is in part prevented by the fact that the recipient's corpuscles are protected by its own serum; *i.e.* the protective serum.

Vincent's method of determining the Moss grouping of blood. Because of the technical difficulties of grouping bloods in a private home without any laboratory facilities, Vincent worked out a method by which a patient's blood group can be determined in from three to five minutes, requiring no laboratory facilities.

In making the test, one must have on hand a stock serum from an individual whose blood belongs to group II and from one in group III. These stock serums are obtained by drawing blood from an individual in group II and from one in group III. The serum is separated from the blood by centrifuging or allowing the blood to clot, the serum from which is placed in a sterile bottle. The serum is preserved by adding to it enough sodium citrate to make a 1.5% solution, and chloroform is added to the extent of 0.3%. These serums, if kept sterile, can be kept indefinitely.

Technique of grouping the blood. One drop of group II serum is placed on a glass slide near one end, and one drop of group III serum on the same slide near the other end. A drop of blood from the person to be grouped is mixed with each of the serums on the slide and the reaction noted. Clumping of the corpuscles, if it takes place, will occur in from one to three minutes, and can be readily seen with the naked eye. The various groups will be noted by the following reactions:

1. If agglutination of the corpuscles takes place in the group II serum and not in the group III serum, the blood being grouped belongs to group III.

2. If agglutination is noted in the group III serum and not in the group II serum, the blood being grouped belongs to group II.

3. If agglutination is noted in both group II and group III serums, the blood being grouped belongs to group I.

4. If agglutination does not occur in either serum, the blood being grouped belongs to group IV.

In noting the reaction, if by simply looking at the slide with the naked eye, there is any doubt as to whether or not agglutination has taken place, this can be definitely determined by placing the slide under the microscope. From the above, it may be noted that if one has on hand a stock serum belonging to group II and to group III, the technique of grouping blood is very simple, and can be done in a few minutes, even without any laboratory facilities. The simplicity and rapidity with which it can be done is the only advantage it has over Brem's technique as previously described.

The determination of the hemolytic reactions of blood by the Moss method in the selection of donors has proven very satisfactory in our hands. Since adopting this method, over two hundred and fifty transfusions have been made, encountering only one case of hemolysis. The milder reactions have been rare. These have been manifested by a chill in five per cent. of cases, and by temperature occurring on the same or following day in ten per cent. of cases.

Except in extreme emergency cases, one is never justified in making a blood transfusion without first having made a hemolytic test between the two bloods to be mixed. Even between near relatives, such as sister to sister, or parent to child, etc., severe fatal hemolysis may occur from mixing the two bloods. In case of a large family in which the father and mother are not in the same blood group, usually some of the children will be in the same group as the mother, and some in the father's group, and occasionally some in still another group. Thus it is plain that a brother might be a suitable donor for one brother, but not for another; also he might be a suitable donor for one parent and not for the other, thus making it a dangerous procedure to transfuse one member of a family from another member without first determining the hemolytic action of one blood with the other.

METHOD OF TRANSFUSION

In selecting a method of transfusion of blood, one should choose a technique which is safe and simple and which will deliver plain, whole blood into the vein of the recipient in as near its normal state as is possible.

The direct method of transfusion—bringing intima to intima—would be the ideal method, were it not for the fact that it requires expert surgeons to perform the operation, and that there is no way of determining with any degree of accuracy the quantity of blood transfused. On account of the technical difficulties of the operation, the direct methods of transfusion have been almost entirely replaced by the various indirect methods, the technique of most of which is more simple.

Author's method of transfusion. (Percy.) The method is an indirect, closed method and consists of drawing blood into a specially designed glass tube, then injecting it into the vein of the recipient. The tube is coated inside with solid grocers' paraffin, and liquid paraffin is floated on top of the blood, preventing the blood from coming in contact with the air.

Description of tube. The tube to be described is a modification of the Brown tube, which was modified with the object of making a venous transfusion tube, and also a tube more easily constructed. It consists of a glass cylinder 5 cm. in diameter, with a cannula leading from one end, the other end being drawn out into a tube about 1 cm. in diameter, to which a Y connection containing a two-way valve is made. To one arm of the Y a rubber tube is attached for suction, to aid in filling the tube, and to the other arm a rubber bulb is connected, to aid in injecting the blood. The tube differs from the Brown tube in that there is no side tube coming off from the cylinder, and the upper end of the cylinder, instead of being closed with a large cork, is drawn out into a tube for the Y connections as described above. The cannula part of the tube is so constructed that it can be inserted directly into the vein of the donor and then the recipient. An open dissection of the vein of the donor and recipient is made for two reasons: First, if the operation were done subcutaneously, it would be necessary to use a needle with a rubber connection to the cannula, which connection would make a roughened area that would favour clotting, whereas with the smooth, paraffin-coated cannula there is no such tendency. Second, after the tube is filled with blood, the cannula can be inserted into a vein of the recipient without delay, an essential feature after blood has been withdrawn.

Preparation of tube. The tube should be cleansed by washing with water, alcohol, and then with ether, and, after it is perfectly dry, two ounces of melted grocers' paraffin is poured into the tube through the upper end. It is then wrapped in a towel and placed in a steam autoclave for fifteen minutes under fifteen pounds of pressure, after which, with sterile rubber gloves over the hands, the tube is rolled around while cooling, so that every part of the inside is covered with melted paraffin and any excess allowed to run out of the large end. Care should be taken not to allow the cannula to become plugged with paraffin. If it does, the tip is warmed over a flame and the paraffin allowed to run back into the tube. Sterilizing the rubber tubing, Y valve, and mouth-piece is done by placing them in a towel and autoclaving in the same way and at the same time as the transfusion tube, or boiling them for twenty minutes. The atomizer bulb is thoroughly washed with alcohol to sterilize it. When ready to use, the connections are all made and two ounces of sterile liquid paraffin aspirated into the tube through the cannula by means of suction at the mouth-piece.

A more simple method of sterilizing the tube consists of first pouring the melted paraffin into the tube, then carefully heating the tube over a gas burner until the paraffin in the tube begins to smoke. The excess paraffin is allowed to run out of the tube, and the tube is carefully rolled with the hands while the paraffin is cooling, thus evenly coating the entire tube.

Technique of transfusing the blood. The arms of both the donor and the recipient are prepared as for surgical operation. Proper constriction of the donor's arm is essential if one wishes to draw off a large quantity of venous blood rapidly. Constriction by means of a rubber tube is not satisfactory because the amount of pressure is not known, nor can the pressure be varied as desired. An ordinary blood-pressure apparatus placed about the arm and pumped up to 50 to 70 mm.

of mercury, depending upon the rapidity with which the blood flows, makes an excellent constrictor. By this means the venous circulation is impeded, but not the arterial, thus making the entire arm a blood reservoir, increasing the pressure in the vein selected.

It is imperative to use a separate set of instruments on different tables for donor and patient, in order not to transmit infections from patient to donor. Under local anæsthesia, using one-half of one per cent. novocaine solution intradermally, an incision is made over the cephalic vein just above the elbow on both the donor and recipient, and a ligature placed about the vein on its proximal portion in the donor, and on its distal portion in the recipient. Small Carrel clamps are placed on that portion of the vein away from the ligature in each patient, and a longitudinal incision 3 mm. long is made through all coats of each vein midway between clamp and ligature. Small retention clamps are placed on the two edges of the incision in each vein in order to hold them open.

Just before the tube is inserted into the donor's vein, about 25 c.c. of sterile liquid paraffin are aspirated into the tube. The cannula is placed pointing distally into the vein of the donor, and the Carrel clamp released from the vein. The blood is well protected from the sides of the glass by the paraffin coat. As the tube fills, the liquid paraffin floats on the blood, thus preventing the blood from coming in contact with the air. As soon as the tube is filled, which in our experience averages about three and one-half minutes to withdraw 600 c.c. of blood, the Y valve is closed, the cannula removed from the vein, and the small clamp reapplied to the donor's vein.

The cannula is now quickly placed in the lumen of the vein of the recipient and the Carrel clamp released. The blood will now flow into the vein of the recipient toward the heart, the velocity of which flow may be controlled by careful pumping of the rubber atomizer bulb. As soon as it is evident that the blood is flowing properly, an assistant may release the constrictor from the donor and ligate the vein distally to the opening from which the blood has been taken. Not more than five minutes should be utilized in obtaining the blood. The tube can be emptied in about a minute and a half, but greater deliberation is advisable so that possible hemolytic phenomena may be noticed, acute dilatation of the heart avoided, and so that aeration of this venous blood may be more ready.

The length of time required to fill the tube with blood varies with different donors. It is well to have two tubes ready, so that if it is found that the first tube fills slowly, taking more than five minutes to get the required amount, the process may be repeated with the second tube, aspirating only the remainder of the required amount of blood.

As soon as the blood has been injected, the cannula is removed from the vein and a ligature placed on the vein just proximal to the little slit in the vein. Skin wound is then closed with horsehair.

Factors of safety. The chief points to be borne in mind in blood transfusion are: the avoidance of hemolysis, air embolism, clot embolism, and acute dilatation of the heart.

The greatest risk from the operation is that from hemolysis. This danger can be avoided in the vast majority of cases if careful hemolytic and agglutination tests are always made preliminary to transfusion. While laboratory methods have their limitations and are not infallible, still, if the tests are always carefully made, the danger from hemolysis is slight.

The danger from air embolus and clot embolus can always be avoided if proper care is exercised in carrying out the technique of the operation.

The danger of acute dilatation of the heart is probably not as great as is generally supposed. So far, the author has not encountered a case in which there was any evidence of the heart having been embarrassed by the transfusion. It is well, however, not to inject the blood too rapidly in very weak and anæmic patients, especially if it be the first transfusion.

Reactions following transfusion. The majority of our patients have not experienced any noticeable reaction whatsoever. In about five per cent. of cases a slight chill has occurred, followed by temperature, and in an additional five per cent. a mild temperature developed the same evening or day following the transfusion. This applies to transfusion in which the patient and donor were in the same blood group, as classified by Moss. Whenever we deviated from this and used a donor from a different blood group than that of the recipient, as was occasionally necessary, the transfusion was usually followed by a marked chill and temperature. A donor from a different group than that of the recipient was never used except when the patient was in one of the rarer groups and it was difficult to find a donor belonging to the same group. In these instances, a donor was chosen from group IV, a group whose corpuscles would not be agglutinated by the serum of the recipient.

ADVANTAGES OF ABOVE METHOD OF TRANSFUSION

1. Known quantities of blood may be administered.
2. As much as 600 to 700 c.c. of blood can be given in from five to eight minutes.
3. Venous blood is utilized so that arteries such as the radial are not destroyed.
4. Transfusion can be made without danger of contaminating the donor with the blood of the recipient.

5. The blood does not come in contact with the air during the entire operation.

6. There is direct communication between vein and chamber by a simple, paraffin-lined glass cannula. There are no metal, rubber, or other connections which might cause resistance to the flow of blood and thus favour the formation of a clot.

7. Plain, whole blood is administered, and in as nearly its normal state as possible. The blood is not diluted with any foreign substance nor traumatized by beating, as in the citrate method, nor is it traumatized by passing through a series of valves and connections, as it might be in some of the other indirect methods of transfusion.

PART II

TRANSFUSION OF BLOOD WITH THE AID OF SODIUM CITRATE

By Richard Lewisohn, M.D., F.A.C.S.

Very great credit belongs to Crile and Carrel, who devised and perfected the method of direct transfusion and who gave the impetus to our modern era of blood transfusion. Their methods, though devised only about ten years ago, are of historical interest only. Direct transfusion of blood has been abolished in this country on account of the cumbersome technic and the impossibility of ascertaining the exact amounts of the transfused blood. Only approximately was one able to gauge the amount of blood transfused by watching the rise of the hemoglobin in the recipient, a method which is very crude and uncertain. Furthermore if clotting occurred in the anastomosed vessels, the result of the operation was most problematical.

All the modern methods of blood transfusion are indirect methods. It has been proven beyond doubt that transfusions done by the so-called indirect route are just as efficient as those done by vessel anastomosis. Their superiority is based, 1, on the possibility of ascertaining exactly the amount of transfused blood, and 2, the simplification of the technic.

The technical simplicity of the citrate method is based upon the fact that coagulation of the blood during the transfer from donor to recipient is absolutely prevented by mixing the blood with an anticoagulant, i.e. sodium citrate. The attempts to use an anticoagulant are not of recent date. Experiments along these lines had been made by different investigators in the last century. However, they all came to the conclusion that such anticoagulants in the amounts required were too toxic for the human body.

Experiments which I published in 1915 showed that a very minute dose of sodium citrate (i.e. 0.2%) is sufficient to prevent coagulation of the blood for two days. Furthermore these experiments showed the absolute atoxicity of such citrated blood for the human organism, even when large amounts of blood (for instance 1,500 cubic centimetres)

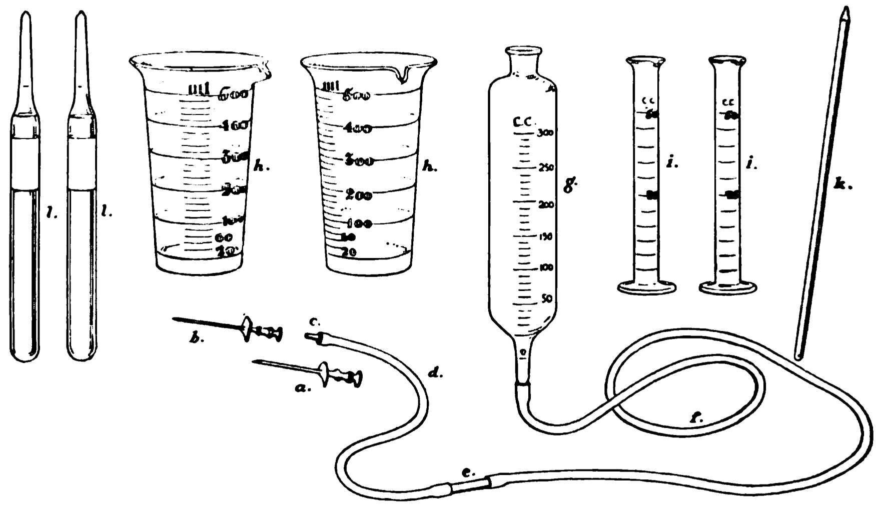


FIG. 164. COMPLETE OUTFIT FOR TRANSFUSION OF BLOOD WITH THE AID OF SODIUM CITRATE. (*Lewisohn.*)

are required in cases of profuse hæmorrhage. The coagulation time of the recipient's blood is temporarily shortened. Thus citrated blood can be used safely and advantageously for any form of blood disease, with the same clinical results as those derived from uncitrated blood.

TECHNIC OF BLOOD TRANSFUSION WITH THE AID OF SODIUM CITRATE

The outfit for a blood transfusion consists of two small glass jars (Fig. 164, *i*), two large glass jars (*h*), two glass ampoules, containing 50 cubic centimetres of a sterilized 2.5% solution of sodium citrate (*l*), one large-size cannula for taking the blood from the donor (*a*), one smaller size cannula for the injection of the blood into the recipient (*b*), one glass rod (*k*), and a salvarsan flask (*g*) with rubber and glass taper connect (*c, d, e, f*)).

The blood is taken from the donor in the following manner:

The arm is washed with soap and water and alcohol. If the veins are clearly visible, iodine may be used for sterilization of the skin. A tourniquet is applied to the arm, causing moderate constriction. A vein in the elbow region is punctured with the cannula of large diameter. It is important to insert the cannula properly into the vein, so that the blood runs through it rapidly in a large stream. If difficulty is encountered in the proper insertion of the cannula, the vein may be exposed through a small incision. The blood is collected in the large glass jar. This glass jar contains at its bottom half the quantity of citrate solution needed for

FIG. 165. TAKING BLOOD FROM THE DONOR. (*Lewisohn.*)

the transfusion. In other words, if 500 cubic centimetres of citrated blood are needed, we pour 25 cubic centimetres of citrate solution into the large glass jar and add the residual 25 cubic centimetres after we have collected 250 cubic centimetres blood.

The blood is gently stirred with a glass rod to ensure its proper mixture with the anticoagulant. After the collection of the required blood volume, cannula and tourniquet are removed and a few drops of collodium or gauze compression are applied to the puncture hole.

The recipient's vein is usually exposed through a small incision. The cannula of smaller calibre is introduced, the salvarsan flask attached to the cannula, and the citrated blood poured into the glass flask. As a rule 50 cubic centimetres of saline solution are run through the tubing in order to prevent air bubbles from getting into the circulation of the

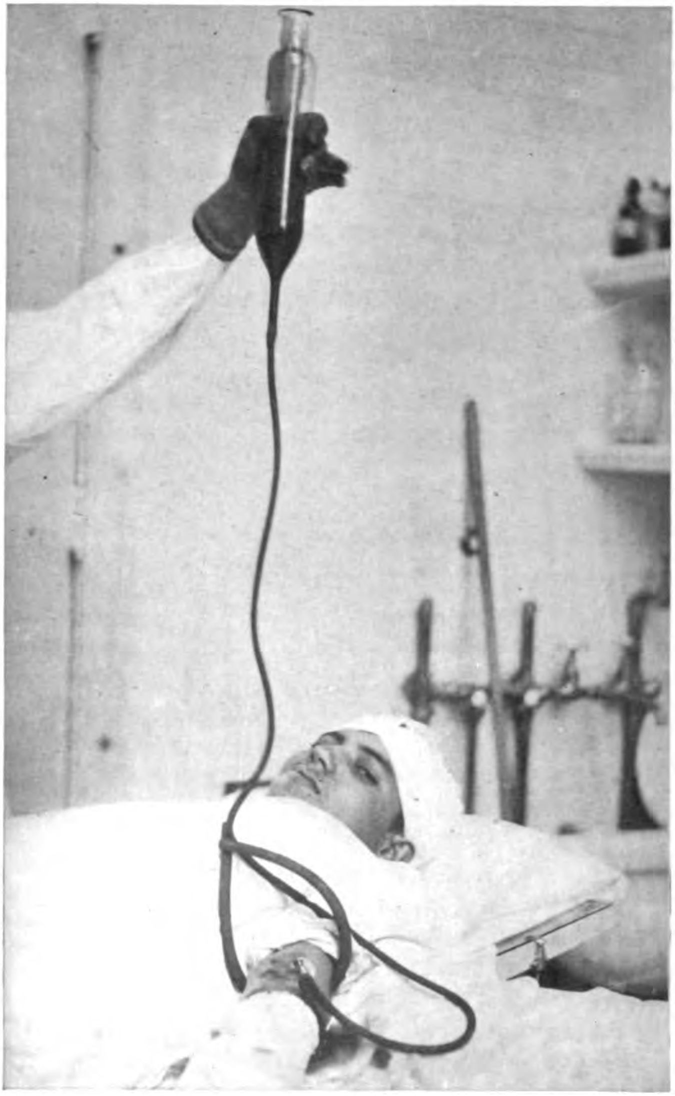


FIG. 166. INFUSION OF THE CITRATED BLOOD INTO THE RECIPIENT. (*Lewisohn.*)

recipient. The technical steps for the injection of the blood into the recipient are exactly the same as those for an intravenous infusion of salt solution.

TESTING DONORS FOR TRANSFUSION

The development of proper tests for testing donors and recipient as to the mutual quality of the blood has made blood transfusion an absolutely safe procedure. Formerly serious accidents, even deaths, occurred from incompatibility of the two bloods. This has been discussed above and need not be repeated here, but it should be remembered that just as great care should be used in this method as in any other.

Blood relatives (father, mother, son, etc.) have to be tested just as carefully as strangers. The idea that blood relatives of the recipient do not require a test is erroneous. The only exception to the rule is the fact that in new-born infants the mother's blood can be safely used without previous tests (Cherry and Langrock).

The same donor should not be used for a second transfusion without another test. Following a transfusion from one donor, the blood of other suitable donors has to be tested again before a subsequent transfusion is given, as the recipient's blood may have been altered by the first transfusion (Libman and Ottenberg).

Indications. Blood transfusion has always appealed to the imagination not only of the laity but of the medical profession. It is therefore not surprising that transfusion of blood as a therapeutic agent has been suggested for a great variety of diseases.

Two groups will always stand out as the great domain for blood transfusion: acute hæmorrhages and the hæmorrhagic diseases.

For acute hæmorrhages by traumatism or rupture of a large blood vessel (bleeding gastric ulcer, ruptured ectopic, typhoid hæmorrhage, etc.) blood transfusion is the remedy par excellence. Saline infusion is a very poor and inefficient substitute for blood. Lately 7 per cent. acacia solution has been suggested by Bayliss. This may be of some value in raising the blood pressure. Its effects upon the system can certainly not be compared with the beneficent effects of an infusion of blood into an exsanguinated patient.

In every severe case of typhoid fever a tested donor ought to be on hand for the emergency which may arise at any moment. The mortality of typhoid fever could thus be decreased materially.

Williams has lately again pointed out its great value for injuries on the battlefield. In the present war blood transfusion seems to be used quite extensively, judging from different articles on this subject which have appeared in European medical journals.

Second in value and efficiency is the transfusion of blood in hæmorrhagic diseases (hemophilia, purpura, and allied conditions). In typical cases of hemophilia, blood transfusion is a very efficient remedy. I have seen a number of cases, where serum and coagulen had been tried without effect and where transfusion of foreign blood stopped the hæmorrhage instantly. Results in cases of purpura have not been quite as satisfactory. In quite a few cases, specially those of persistent metrorrhagia in young women, which belonged clinically to this group, repeated transfusion of blood, taken from different donors, failed to stop the hæmorrhage.

One of the most gratifying fields for blood transfusion is in hemophilia neonatorum. The babies are usually brought to the hospital by the father in a very exsanguinated condition. The mother's blood is the only one available without tests (see above). We therefore send a member of the house staff to the parent's home and 100 to 150 cubic centimetres of blood are taken from the mother. The citrated blood is then carried back to the hospital and injected into one of the arm veins of the baby through a small incision of the skin. Hæmorrhage stops immediately after the transfusion and, furthermore, these babies are permanently cured. The intramuscular injection of horse serum, which has been suggested by Welch as a cure for these cases, failed to stop the bleeding in a few cases which responded subsequently to transfusion. One injection of serum may be tried. However, if the hæmorrhage does not cease, blood transfusion should be resorted to as an absolute and permanent cure for these cases.

We have used transfusion of blood quite extensively as a pre-operative procedure and our results in this line have been very gratifying. Patients who have to undergo an extensive operation and who are in a weak condition from the underlying disease, ought to be transfused. They will thus stand even very long operations remarkably well.

Another field for the use of transfusion is cholemia, either pre-operative or post-operative. The alarming post-operative oozing of a jaundiced patient, who has suffered from a common duct stone, can often be stopped instantaneously by transfusion.

We need not enter very extensively into a discussion of the value of blood transfusion in leukæmia and pernicious anæmia. The great enthusiasm with which permanent results of cure were claimed for blood transfusion in these very serious diseases of the blood has gradually vanished. We must grant that we can hardly expect real cures. However, by repeated transfusions the life can be prolonged for one to two years. In the beginning of the disease the clinical results of transfusion are most startling. In the later stages or after repeated injections of blood the results leave much to be desired and are often hardly worth the efforts.

It has been the endeavour of the medical profession for many centuries to cure the different forms of sepsis by blood transfusion. Our results in puerperal sepsis have been absolutely negative. On the other hand otogenic and other forms of sepsis will often respond remarkably well to this treatment.

Blood transfusion represents the treatment par excellence for CO-poisoning. It has been used repeatedly in tuberculosis. The results do not seem to be very promising.

CHAPTER V

LIGATURE OF ARTERIES

GENERAL CONSIDERATIONS

LIGATURE of an artery in continuity is an operation that at the present time does not receive as much attention as was devoted to it in former years. With the introduction of asepsis the good effects of the improvement in surgical methods were shown in a striking manner in the results of the ligature of arteries. Up to that time there were two great risks attached to these operations which were peculiar to them; they were secondary hæmorrhage and gangrene of the limb. The most gratifying results followed the use of aseptic precautions, and secondary hæmorrhage practically disappeared from the complications of the operation. It is true that secondary hæmorrhage may still occur after ligature of the largest arteries, in spite of all precautions to the contrary, but it has become evident that in the vast majority of cases the cause of secondary hæmorrhage was really sepsis, and that if this can be avoided many of the elaborate precautions laid down by former writers on the subject are unnecessary. Similarly, it was soon discovered that the occurrence of gangrene in the limb is far less frequent when aspesis is attained, and it became clear that sepsis plays an important part as an exciting cause of gangrene. The septic inflammatory swelling that often followed ligature of a main vessel was sufficient to embarrass the circulation and precipitate gangrene. Since the introduction of aseptic methods it has been found that not only the main artery but also the main vein may be ligatured without risk of gangrene, and the two vessels may even be tied simultaneously with a fair chance of gangrene being avoided, provided that the wound remains aseptic.

Moreover, the treatment of aneurysm has undergone a considerable revolution, mainly as a result of the introduction of aseptic methods, and the more radical methods of dealing with the aneurysm by cutting directly down upon it and either extirpating the sac entirely or dealing with it by some such method as Matas's operation (see p. 382) make ligature in continuity less frequently done than it was in former times. Finally, the application of aseptic methods to wounds has largely banished that form of secondary hæmorrhage accompanying fractures or wounds of vessels which necessitated ligature of the main trunk before it could be controlled; the surgeon's confidence in his aseptic methods is now so great that he would never think of trying to treat a wound of a large vessel by pressure in preference to a careful exploration of the parts under the control of an Esmarch bandage in order to identify and ligature the bleeding points.

For all these reasons ligature of arteries in continuity has come to occupy quite a secondary position in modern surgery. The operations still have to be done under certain circumstances, however, and many of them have to be performed under circumstances of peculiar danger and difficulty. Owing to various exigencies connected with the supply and preservation of subjects, these operations still form the bulk of those set at examinations, and their consideration must therefore be gone into fully. Before dealing with the exposure and ligature of the individual vessels, it will be well to enumerate a few important principles applicable to the ligature of vessels in general.

Exposure of the artery. In many instances the artery is exposed by an incision which lies directly over its anatomical line, and there are many cases—such, for instance, as ligature of the upper third of the anterior tibial—in which accurate definition of this line makes all the difference between an easy and a difficult operation. In other cases, such as the posterior tibial, the anatomical line is disregarded by the surgeon and a set incision is made which experience has shown to be the easiest for the purpose. In all cases great importance should be attached to the proper placing of the incision, as it is difficult to rectify a mistake made in this respect without doing unnecessary damage.

The length of the incision should always be directly proportionate to the depth from the surface at which the vessel lies. This will therefore vary not only with the particular artery to be tied, but with the fatness or muscularity of the individual patient, and is a point that must always be taken into due consideration. An artery that can be exposed quite easily through an incision two inches long in a spare person would probably be quite inaccessible through a similar incision in a very fat or muscular one. In all cases the incision should be sufficiently long to enable the surgeon to carry out his manipulations with ease, but it must not be unduly long, as this is not only unskilful but may expose important structures to injury. The lengths of the incisions given in the following chapters are approximate only and apply to subjects of medium development.

The line of incision may, if the surgeon likes, be planned very accurately by marking upon the patient's skin the anatomical landmarks by which it is determined. This, however, is not necessary, as it is usually sufficient to make an assistant place his fingers upon these landmarks; the surgeon then draws an imaginary line between them and can thus plan his incision very accurately. It is essential, also, that, when taking the anatomical line, the limb should be in the position in which it is to lie when the operation is performed. Thus the line for the femoral artery (see p. 444) varies considerably according to whether the limb is flexed, abducted, and rotated outwards, or whether it lies flat upon the table.

There are a few points to be attended to in actually making the incision down to the artery. The knife, which should be held as shown in Fig. 167, should be made to cut strictly at right angles to the surface of the skin, so that its edges are not bevelled, and every incision of the deeper structures should be exactly the same length as the cutaneous one. This ensures the surgeon ample room if the skin incision is long enough

Fig. 167. Correct Method of holding the Knife when cutting down upon an Artery.

originally, and he will therefore not fall into the error of making a conical pit in which he will find it extremely difficult to work. All incisions should be made with as clean a cut as possible and without any displacement of parts. Should it be desirable to retract the edges of the wound, this should be done equally on the two sides, unless there be some definite reason for pulling the wound to one side rather than to the other. There is no more fertile source of error in operating upon the dead subject than retraction of the wound to one side; it leads the operator to work towards that side until he eventually travels hopelessly away from the line of the vessel he is seeking.

No director or tearing instrument should be employed, the point of the knife being used to divide the tissues, which should be picked up in fine-toothed forceps and damaged as little as possible. Intermuscular septa must be looked for and identified with the greatest care and gentleness. In the living subject they are not so difficult to find as they are in the cadaver. The unequal contraction of the different muscles and the presence of fat and emergent vessels generally render the identification of intermuscular septa in the living a comparatively easy matter if due search be made for them. In the dead subject, however, there is nothing easier than to make an artificial intermuscular septum at any particular point, especially in the bodies preserved with formalin, in which the pallor of the muscular fibres and their friability are very misleading and tempt the operator to find or to make intermuscular septa where none exist. When the desired intermuscular septum has been reached, the knife should be no longer used, but the septum opened up with a blunt instrument, such as a fine spatula or dissector, until the finger can be inserted, when the latter is swept up and down and forms a most effectual muscular separator. When the septum has been opened up, the limb should be arranged so as to relax the muscles concerned to the utmost extent, and these should be kept out of the way by broad spatulæ used as retractors, which keep the muscles back better than the usual fenestrated retractors and at the same time are useful in reflecting light from outside into the depths of the wound, a point of considerable importance when such a vessel as the anterior tibial has to be picked up deep down on the interosseous membrane. It is in cases like this that a powerful forehead-light is of the greatest assistance; in some of the deeper-seated arteries the operation is most difficult without its help.

The identification of the artery is, or should be, quite easy in the living subject; it pulsates, and that should suffice for its identification anywhere. If not, its characteristic yellow elastic appearance cannot be well mistaken for anything else. In the dead subject, however, the identification is more difficult, but here its dead white colour, with the characteristic flat groove along the centre of its anterior surface, and its tough feel are sufficient to make a mistake improbable.

Ligature of the artery. Before the artery can be tied, certain steps must be taken to ensure that only the vessel is included in the ligature. There are nearly always important structures in intimate relation with the various vessels, such as veins, nerves, muscles, and other structures, and these have to be separated from the artery and pulled aside before the ligature is passed. Appropriate directions will be given in the following pages for each individual case. Here it is sufficient to make the general remark, that when there are venæ comites which closely surround the artery and anastomose across it, as is the case with the arteries below the knee and the bend of the elbow, it is best to pass the ligature around both artery and veins; attempts to separate the two structures invariably end in the most troublesome oozing, owing to the free anastomosis of the veins across the artery, and there is no increased risk of gangrene occurring from the obliteration of the venæ comites with the main artery.

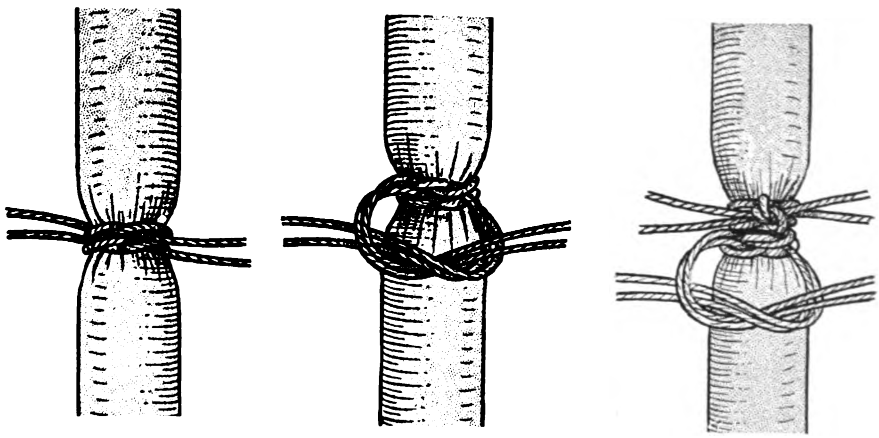
When, however, the artery possesses a well-defined sheath, as it does from the popliteal and brachial arteries upwards, this must be opened and the artery within it properly cleared before the ligature can be passed successfully. The sheath of the artery is a well-defined structure and there is a definite loose cellular interval between it and the wall of the vessel. In this the needle can be easily introduced close to the wall of the artery without the risk of any other structure being included, provided always that the point of the needle be kept well within the sheath. Important structures, such as the vein or nerve, usually lie outside the sheath, and this precaution alone, if properly adhered to, is sufficient to save them from inclusion in the ligature. At the same time, clearing the artery must be done carefully if it is to be done successfully. The classical way is to pinch up a small fold of the sheath with forceps parallel with the long axis of the vessel. The knife, held quite horizontal, is made to cut this small elliptical piece out of the sheath. One edge of this opening is now seized in fine-toothed forceps, and the point of the aneurysm needle is insinuated by gentle lateral movements between it and the adjacent wall of the artery until it has been passed half-way round the vessel on that side. It is then withdrawn, the opposite side of the incision in the sheath is seized and steadied, and the aneurysm needle is inserted between it and the artery, and a similar procedure is carried out until in this way the artery has been separated from its sheath round its whole circumference. Finally the needle is passed from the appropriate side between the artery and the sheath, the forceps steadying the corresponding edge in the incision in the sheath meanwhile.

Particular stress was laid by former writers upon the necessity for delicacy and care in performing this little operation. For instance, the operator was warned that on no account should he denude the artery of its sheath for more than a quarter of an inch, lest the nutrition of the vessel wall should be interfered with and secondary hæmorrhage should result. For a similar reason the vessel was not to be lifted out of its bed. We now know that neither of these points are of any practical importance, however much a rigorous observance of them may conduce to neatness in operating. In practice, therefore, the surgeon will clear the artery in such a manner as to enable him to pass the ligature between the vessel and its sheath with ease and without using any force. Any violence is almost certain to result in a contretemps of a serious nature, such as transfixion of the vessel wall or wound of some important neighbouring structure, such as the vein or the pleura. The surgeon should have at hand aneurysm needles with various curves and bent at various angles. He may even have recourse to a probe, which can be bent to a suitable angle and upon which the ligature can be threaded.

The next important point is the question of *the material for ligature* and the method in which the ligature should be applied. Many different materials have been advocated from time to time, but the one that holds the field is silk; this can be rendered absolutely sterile by boiling, and therefore there need be no fear of its being the cause of sepsis or secondary hæmorrhage. The ordinary Chinese twist is generally used, and a moderate-sized thread will be required for ligature of most of the arteries. These are occluded by pulling the ligatures sufficiently tight to divide the inner and middle coats; this gives a characteristic sensation which cannot be mistaken. The first loop of the ligature is drawn tight in the ordinary way, and then the traction is kept up until the coats are felt to give way, when the second loop of the ligature is tightened. Care must of course be taken to tie a true reef-knot and not a 'granny'. Thus the traction required to divide the inner and middle coats necessitates the use of rather stouter silk than would be necessary were the vessel walls merely approximated.

Simple approximation of the vessel walls has been strongly advocated by Ballance and Edmunds (*Ligation in Continuity,* London, 1891) as a substitute for division of the inner and middle coats in all the larger arteries. Their experiments tend to show that, while simple approximation is sufficient to cause immediate and permanent occlusion of the vessel, it possesses the great advantage over division of the coats that there is no damage done to the arterial wall, which is as capable of withstanding the high arterial pressure as it was before ligature. As a matter of practice it is found immaterial whether or not the vessel walls are divided in the arteries below the common femoral, and, since it is easier to divide the coats than to approximate them carefully, this method of ligature is in general use for ligature of the superficial femoral and the third part of the axillary and all the branches below these vessels. Above these points, however, the pressure to which the damaged arterial wall will be exposed after division of its coats is so great that secondary hæmorrhage due to this mechanical cause is likely to occur even in an aseptic wound, and therefore simple approximation without division of the coats is distinctly preferable. For this purpose Ballance and Edmunds (*loc. cit.*) recommend the use of multiple ligatures of soft floss silk tied in what they term a 'stay-knot' (see Fig. 168). In this method at least two ligatures are employed; if more are used, as may be the case in large arteries such as the innominate, they should be arranged in pairs.

The proximal of the two ligatures is first tied in a single loop and its ends are held on the stretch by an assistant just sufficiently tightly to bring the vessel walls together and check the pulsation on the distal side. This acts as a breakwater while the second ligature is made to approximate the vessel walls in a similar fashion; the two ligatures are applied closely side by side. The two ends of the primary loops of each ligature are then taken by the operator in each hand and are tied together to form the second loop of the knot (see Fig. 157). This makes a single flat knot which lies well upon the middle of the silk and does not press against the vessel wall as it pulsates. One reason for



A B C

FIG. 168. THE 'STAY-KNOT' OF BALLANCE AND EDMUNDS. In A the first loops of the two ligatures have been tied. In B the two ends on each side are made to form the second loop of the knot, which is shown completed in C, in which a second pair of ligatures is being applied beyond it.

using double ligatures is that it ensures perfect stoppage of the blood-stream. With a single ligature it is almost impossible to approximate the vessel walls accurately without dividing them, and, unless the approximation be perfect, the circulation will go on in spite of the ligature. By applying the ligatures in pairs the second can be tightened, whilst the first acts as a breakwater and takes the full force of the circulation, and therefore there is little chance of the second ligature stretching during the tying of the second knot. Another reason for the double ligature is that, owing to its breadth, it keeps the knot from being pressed upon by the expansile vessel wall; this Ballance and Edmunds found to be a fertile source of secondary hæmorrhage. For the large vessels it seems obviously a good plan to employ as wide a ligature as possible. and for this purpose two, three, or even more pairs of ligatures applied in this manner may be useful.

The aneurysm needle is always passed round the vessel unthreaded. When a double ligature is to be applied this can be done by passing and withdrawing the needle once. When four or six are used it will probably be advisable to provide a needle with a particularly large eye into which all the ligatures can be threaded, as in vessels of the size of the innominate the frequent passage of an aneurysm needle around it is likely to be fraught with some danger. If no special needle of this kind be at hand the difficulty can be got over by passing a loop of silk round the vessel and threading through the loop the number of ligatures that are to surround the vessel. These are then pulled into place by withdrawing the loop.

Difficulties and dangers. There are of course many special difficulties and dangers connected with the ligature of individual arteries, which will be duly pointed out and the best means for avoiding them indicated in connexion with the particular operations in which they may arise. The only dangers common to all operations of this sort to which attention need be directed here are inclusion of other structures within the ligature, and wound of the companion vein. Of these dangers the first can obviously only be avoided by anatomical knowledge and careful operating. The surgeon should know what structures are to be avoided and where they are situated. A wound of the companion vein is an accident that is likely to occur in many situations. In some arteries, such as the popliteal and the lower part of the femoral, the vein is very closely adherent to the artery, and is easily pricked unless great care be taken. The best way of avoiding this accident is always to pass the needle from the vein, *i.e.* between the vein and the artery. This ensures the point of the needle being kept in strict contact with the wall of the artery for at least that portion of its course during which the vein is likely to be encountered. The time at which accidents usually occur is when the point of the needle is being made to emerge from the hole in the sheath after it has passed round the vessel. Should its point be allowed to get outside the sheath damage is sure to be done.

The treatment of this somewhat alarming accident is very simple. The needle should be withdrawn at once and no further attempt should be made to tie the artery in this situation. As a rule the hæmorrhage in the vein stops readily, particularly if the artery be ligatured at a fresh spot either above or below the point at which it was originally proposed to do this. Should the wound in the vein go on bleeding, either a lateral ligature may be put on or the wound may be sewn up with a fine continuous suture (see p. 379); this will probably stop the bleeding without interfering with the circulation through the vein.

After-treatment. Whenever the artery ligatured is an important one the most stringent precautions must be taken against gangrene. The entire extremity should be thoroughly purified as if for operation, so that if gangrene occur sepsis shall not find entrance from outside. It is then enveloped in an aseptic dressing surrounded by a large mass of cotton wool several inches thick laid on quite evenly, and loosely bandaged on. The extremity is raised upon a suitable pillow or rest and is kept as warm as possible. It is a good plan to sling the limb and to alter the sling from day to day so as to prevent prolonged pressure upon any one point. The patient should not be allowed to move the limb for at least three weeks after the operation.

LIGATURE OF THE ARTERIES OF THE LOWER EXTREMITY

CHAPTER VI

LIGATURE OF THE ARTERIES OF THE FOOT AND LEG

LIGATURE OF THE DORSALIS PEDIS ARTERY

Indications. Very few; the operation is practically a dissecting-room exercise.

(i) It may be required for a *wound* of the vessel. Firm pressure should be applied over the line of the artery on the proximal side of the wound, which is then enlarged and the divided ends ligatured.

(ii) It has been resorted to in order to stop *secondary hæmorrhage* from a septic wound of the sole; in these cases the posterior tibial artery should be secured behind the inner ankle at the same time.

(iii) It has been done for *traumatic aneurysm* of the vessel. The best plan in these rare cases is to secure the vessel on either side of the aneurysm and then to excise the latter completely.

Surgical anatomy. The dorsalis pedis is the continuation of the anterior tibial artery, and extends from the mid-point between the two malleoli on the front of the ankle to the upper end of the first interosseous space, through which it passes into the sole between the two heads of the first dorsal interosseous muscle. In its course the artery lies successively upon the anterior ligament of the ankle-joint, the head of the astragalus (talus), the superior astragalo-scaphoid (talo-navicular) ligament, the ligaments between the middle (second) and internal (first) cuneiforms, and part of the latter bone. It is covered by the skin and fascia, containing branches of the musculo-cutaneous (superficial peroneal) and anterior tibial (deep peroneal) nerves and the internal saphenous vein, and the upper part of it lies beneath the lower part of the anterior annular (crucial) ligament of the ankle, while below, near its termination, it is crossed obliquely by the innermost tendon of the extensor digitorum brevis. It lies between the tendon of the extensor hallucis longus internally and the innermost tendon of the extensor digitorum longus externally; between the latter structure and the artery is the anterior tibial (deep peroneal) nerve. The vessel is accompanied by venæ comites, one on either side (see Fig. 169).

The artery gives off its lateral tarsal branch just after it emerges from beneath the anterior annular (crucial) ligament, and its metatarsal (arcuate) branch just before it dips down into the first interosseous space. It may be tied anywhere between these two points; the ligature is usually applied at the point where the artery is crossed by the innermost tendon of the extensor brevis, viz. just before it passes into the first interosseous space.

FIG. 169. THE DORSALIS PEDIS ARTERY. On the left-hand side is seen the tendon of the extensor hallucis longus. On the opposite side the innermost tendon of the extensor digitorum communis is pulled back by the retractor. The artery is seen with a vena comes on each side; external to the outer one lies the anterior tibial (deep peroneal) nerve.

Operation. An assistant holds the foot resting firmly on the heel and somewhat plantar-flexed, so as to make the extensor tendons prominent. The surgeon stands to the outer side of the limb and makes an incision an inch long parallel with and just external to the tendon of the extensor hallucis longus when that can be identified; in cases of doubt the anatomical guide-line (see Fig. 170) given above should be followed. The incision is generally made over the lower end of the artery, terminating below over the upper end of the first interosseous space, but it may be anywhere along the line of the vessel.

This incision is deepened carefully in order to avoid wounding the tendon sheaths. The interval between the tendons of the first and second toes is identified and opened up by dividing the dorsal fascia of the foot, and a little dissection will then reveal the artery with its venæ comites, and the very narrow tendon of the extensor digitorum brevis crossing it (see Fig. 169). This tendon may be drawn either downwards or to the inner side, and the ligature is passed from the outer side. It is as well to include the venæ comites in the ligature, as they are often difficult to separate from it. The anterior tibial (deep peroneal) nerve lies well to the outer side of the artery, almost under the innermost tendon of the extensor digitorum longus, and is often not seen.

It is better to seize the artery in two pairs of Spencer Wells's forceps, divide it between them, and then to tie each end separately, than to ligate the vessel in continuity.

Difficulties. The artery is very variable both in its size and its course. It may be wanting altogether; it not infrequently runs well to the outer side of its normal line, and between its points of origin and termination it may form a large loop with its convexity towards the outer border of the foot. A watch should be kept for the inner branch of the musculo-cutaneous (superficial peroneal) nerve, which should be avoided if possible. There is no difficulty in exposing the vessel in the living subject, as its pulsations are always to be felt plainly.

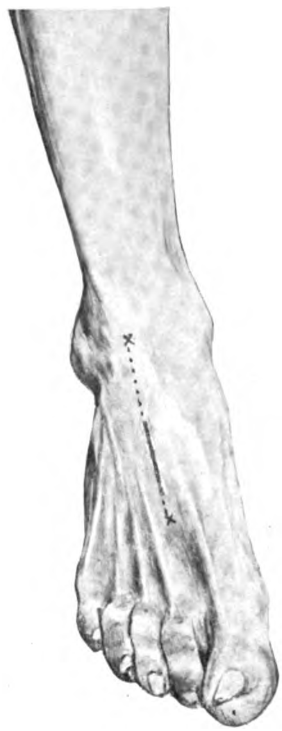


FIG. 170. THE INCISION FOR EXPOSURE OF THE DORSALIS PEDIS.
The upper × is on the mid-point between the two malleoli, the lower on the upper end of the first interosseous space. The dotted line marks the anatomical line of the artery, the thick continuous one the incision for its exposure.

LIGATURE OF THE ANTERIOR TIBIAL ARTERY

Indications. This vessel is very rarely tied, and when ligature in continuity is practised, it will be for—

(i) *Aneurysm,* either spontaneous or traumatic; both affections are rare.

(ii) More frequently the vessel will require ligature for a punctured or a gunshot *wound* or a laceration resulting from a fracture of both bones of the leg. In these traumatic cases the best operation will not be ligature in continuity, but exposure and ligature of the divided ends. An elastic tourniquet round the thigh is of great service under these conditions in controlling the bleeding until the vessel has been exposed and secured.

Surgical anatomy. The vessel extends from the lower border of the popliteus muscle to the centre of the front of the ankle, and its course is denoted by a line drawn from the mid-point between the head of the fibula and the outer tuberosity of the tibia to the mid-point between the two malleoli on the front of the ankle (see Fig. 171). It is deeply placed in the upper two-thirds of its course, passing forwards from the calf over the upper edge of the interosseous membrane between the two heads of the tibialis posticus (posterior). It lies upon the anterior surface of the interosseous membrane, to which it is connected by delicate fibrous bands, as far down as the junction of the middle with the lower thirds of the leg, when it becomes more superficial and lies on the front of the tibia and the anterior ligament of the ankle-joint. In the upper third of the leg the vessel has the extensor digitorum longus on its outer and the tibialis anticus (anterior) on its inner side; in the middle third it lies between the extensor hallucis longus externally and the tibialis anticus (anterior) internally, while in the lower third the tendon of the extensor hallucis longus crosses it obliquely from without inwards, so that the termination of the vessel lies between that tendon internally and the innermost tendon of the extensor digitorum longus on the outer side. It is here covered by the anterior annular (crucial) ligament of the ankle-joint; in the upper two-thirds of its course it is overlapped by the muscles between which it lies.

FIG. 171. LANDMARKS FOR THE ANTERIOR TIBIAL ARTERY. The two upper dots are placed upon the head of the fibula and the outer tuberosity of the tibia respectively. The + between them marks the upper end of the guide line to the anterior tibial, which runs down to the + on the centre of the ankle below. The lowest + is over the upper end of the first interosseous space.

The anterior tibial (deep peroneal) nerve lies at some little distance to the outer side of the artery in its upper fourth. It then approaches the vessel and lies over it, but rather to its outer side, throughout the middle two fourths, while in the lower part of its course it is on the outer side again, intervening between the vessel and the innermost tendon of the extensor digitorum longus. Two venæ comites accompany the vessel, and anastomose freely across it at short intervals. The musculo-cutaneous (superficial peroneal) nerve lies over the vessel superficial to the deep fascia.

The anterior tibial artery may be tied in the upper, middle, or lower thirds.

LIGATURE IN THE UPPER THIRD

The patient lies on his back with the knee flexed and the limb adducted and rotated inwards; the foot is plantar-flexed while the incision is being made, but dorsi-flexed afterwards. The surgeon stands on the outer side of the limb and makes his incision from above downwards on the right, and from below upwards on the left side. The line of the artery (*vide supra*) is carefully ascertained, and an incision four inches long is made over its upper third, its upper limit being an inch below the mid-point between the head of the fibula and the outer tuberosity of the tibia. This incision only goes down to the deep fascia in the first instance, and then, without displacing the soft parts at all, this structure is slit up throughout the length of the wound strictly in the same line as the skin incision. The next point is to identify the intermuscular septum between the tibialis anticus (anterior) and the extensor digitorum longus. There are two intermuscular septa on the front of the leg, the other being that between the extensor digitorum longus on the inner side and the peronei on the outer, and it is easy to mistake one for the other, as the extensor digitorum longus is very narrow just here. The most certain way to avoid error is to seize each edge of the incision in the deep fascia with forceps in turn, and to separate the subjacent muscle from it with the handle of the knife for an inch on each side; then the fascia is fully retracted and the proper septum can be identified. It is the first one met with external to the border of the tibia—which can always be felt—and it leads almost vertically down to the interosseous membrane and is further marked by numerous emergent muscular arteries, whereas the wrong septum leads downwards and outwards to the fibula and has no emergent vessels. The yellow or 'white line' so often mentioned in textbooks is generally wanting.

As soon as the septum has been identified, the foot is fully dorsi-flexed in order to relax the muscles as much as possible, and the handle of the knife is sunk into the septum, and the tibialis anticus (anterior) is separated from the extensor digitorum longus throughout the length of the wound. If the incision in the deep fascia does not coincide exactly with this septum in direction, it may be necessary to make a transverse incision in the fascia at one end of the wound, as the artery lies deep down on the interosseous membrane and as much room as possible is necessary. The muscles are kept out of the way with large flat retractors—ordinary hook-retractors are useless—and the vessel, with its venæ comites, is seen lying on the membrane (see Fig. 172). The nerve lies well to the outer side and may not come into view. The best plan is to pass the needle round both artery and veins, as the latter anastomose so freely round the former that it is almost impossible to separate them, and a wound of

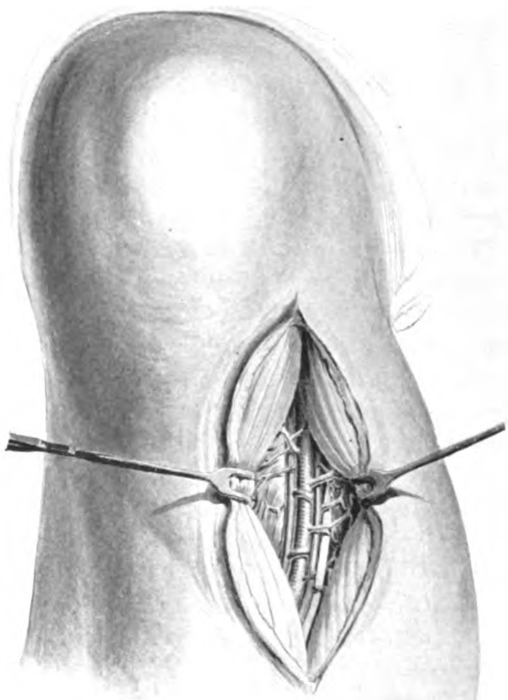


FIG. 172. THE ANTERIOR TIBIAL ARTERY IN THE UPPER THIRD. The tibialis anticus (anterior) is beneath the retractor on the left hand, the extensor digitorum longus beneath that on the right-hand side. The artery, with its venæ comites anastomosing across it, is seen on the interosseous membrane. The anterior tibial (deep peroneal) nerve is seen approaching it obliquely from the outer side.

the veins gives rise to most vexatious oozings. A needle with a very small curve is required; it is best to pass it from the outer side.

Difficulties. The chief difficulty is the identification of the proper septum. If the rules given above be followed exactly, there should be no serious difficulty in finding the vessel. The use of a blunt dissector is to be deprecated, and in no case should the muscular fibres be torn, as that is the surest way of losing all guides to the vessel. Another difficulty is in getting a ligature round the vessel. In actual practice this will hardly ever be necessary, as the operation will be done for a wound, when it is only necessary to tie or twist the divided ends; in these cases a tourniquet should be applied to the thigh before the incision is made. A needle with a curve which is a segment of a very small circle will get over the difficulty best.

LIGATURE IN THE MIDDLE THIRD

Here the vessel lies between the tibialis anticus (anterior) on the inner and the extensor hallucis longus on the outer side. The anterior

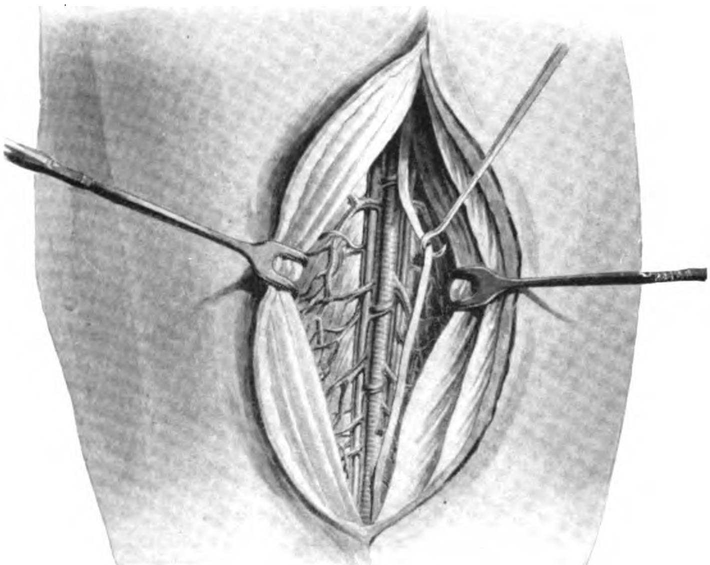


FIG. 173. THE ANTERIOR TIBIAL ARTERY IN THE MIDDLE OF THE LEG. The tibialis anticus (anterior) is retracted on the left-hand side. Beneath the hook of the retractor on the right-hand side is the extensor hallucis longus, while just above it lies the extensor digitorum longus. The artery and its anastomosing venæ comites are seen lying below the anterior tibial (deep peroneal) nerve, which is hooked up from its surface.

tibial (deep peroneal) nerve usually lies over the front of the artery a little to its outer side and is closely adherent to it (see Fig. 173). The extensor digitorum longus muscle, when well developed, overlaps the extensor hallucis longus, so that the latter is not properly seen until the tibialis anticus (anterior) and the extensor digitorum longus have been separated from one another (see Fig. 174).

Operation. The positions of the limb and the surgeon are the same as in the preceding operation. The incision should be three inches long, over the line of the artery, and with its centre opposite the centre of the limb. The skin and deep fascia are incised along the line of the artery throughout the length of the wound. There is nearly always a well-marked intermuscular septum at this level, indicated by a fatty interspace containing emergent vessels. This space is opened up with

FIG. 174. TRANSVERSE SECTION THROUGH THE MIDDLE OF THE LEG TO SHOW THE RELATIONS OF THE ANTERIOR MUSCLES. The anterior tibial vessels are seen lying upon the front of the interosseous membrane. The section shows the arrangement of the three muscles in front of the tibia and fibula. The large tibialis anticus, A, and equally large extensor digitorum longus, D, practically meet so as to conceal the extensor hallucis longus, H, which lies in the triangular interval between them. It will be seen that in this case there is only one septum on the front of the limb, but that it soon bifurcates into two, one lying between the tibialis anticus and the extensor hallucis longus, and the other between the latter muscles and the extensor digitorum longus.

the handle of the knife, and, as the separation proceeds, great care must be taken to keep close to the outer edge of the tibialis anticus (anterior) muscle. When the interosseous membrane is reached, the first structure seen is the anterior tibial (deep peroneal) nerve, which must be carefully separated from the artery. The needle is passed from the nerve, *i.e.* from the inner side.

Difficulties. The chief source of error is missing the septum between the tibialis anticus (anterior) and the extensor hallucis longus, and getting into that between the latter muscle and the extensor digitorum longus. This mistake is avoided by identifying the tibialis anticus (anterior), which is the first muscle external to the tibia, and then keeping close round its outer margin when opening up the intermuscular septum (see Fig. 174).

An aneurysm needle with a small curve is required to pass the ligature

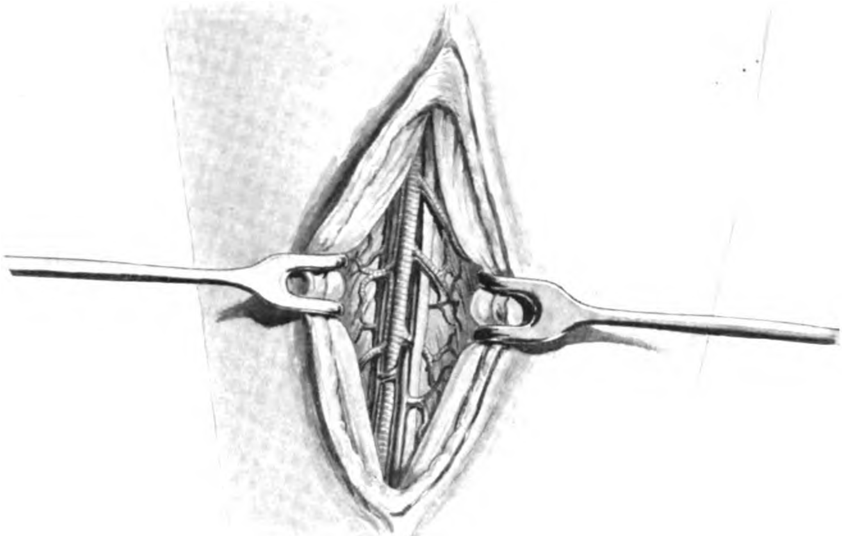


FIG. 175. THE ANTERIOR TIBIAL ARTERY IN THE LOWER THIRD OF THE LEG. The tibialis anticus (anterior) is hooked to the left-hand side, the semitendinous extensor hallucis to the right-hand side. The vessel and its venæ comites are seen with the anterior tibial (deep peroneal) nerve on the outer side.

satisfactorily. The vessel is situated so deeply that passing the ligature is a very difficult matter.

LIGATURE IN THE LOWER THIRD

The tendon of the extensor hallucis longus crosses this part of the vessel and lies to its inner side at its termination, but the artery is generally tied just before the tendon crosses it. The anterior tibial (deep peroneal) nerve and the innermost tendon of the extensor digitorum longus lie to the outer side.

Operation. The position of the operator is as before (see p. 427), but the limb now lies extended, with the toes pointing upwards. An incision an inch and a half long is made over the line of the artery, extending down to just above the line of the ankle-joint. As the incision is deepened, the upper part of the anterior annular (crucial) ligament is divided, and the interval between the tendons of the tibialis anticus (anterior) and extensor hallucis longus is opened up; care must be taken not to open the synovial sheaths of these tendons. The artery is superficial and easy to find (see Fig. 175); if there be any difficulty, it should be looked for beneath the tendon of the extensor hallucis longus. The needle is passed from the outer side, and the divided portion of the annular (crucial) ligament is sutured with fine catgut before closing the wound.

LIGATURE OF THE POSTERIOR TIBIAL ARTERY

Indications. This artery very rarely requires ligature. The indications for it are:—

(i) Gunshot, punctured, or incised *wounds*. These will call for immediate ligature of the divided ends of the vessel in any part of its course. Laceration of the vessel may also occur as a complication of fracture of bones of the leg.

(ii) Traumatic *aneurysm* of the posterior tibial artery has been met with, but is very rare. It may be treated by ligature in continuity, but it would be better to apply Esmarch's bandage to the thigh, expose the aneurysm, secure the vessel on each side of it, and dissect out the sac entire.

Surgical anatomy. This large vessel extends from the lower border of the popliteus muscle to the mid-point between the tip of the internal malleolus and the most prominent part of the os calcis beneath the origin of the abductor hallucis from the internal annular (laciniate) ligament. The vessel lies in the interval between the superficial and deep calf muscles, to the latter of which it is bound down by a special fascia. It lies at first upon the tibialis posticus (posterior), then upon the flexor digitorum longus, and finally upon the posterior surface of the tibia and the posterior ligament of the ankle-joint.

The upper half of the artery is covered by the gastrocnemius and soleus, with the plantaris between them. The lower half is superficial and is covered only by the skin and deep fascia, except at its termination, where it is covered by the internal annular (laciniate) ligament and the origin of the abductor hallucis. The posterior tibial nerve is on its inner side in the upper third, then crosses obliquely behind the artery, and finally lies on its outer side. Two venæ comites accompany the vessel throughout its course and, like those of the anterior tibial, anastomose freely around the artery.

Ligature of the posterior tibial is chiefly a dissecting-room operation, and is done in three situations: (i) In the middle of the calf, (ii) in the lower third of the leg, and (iii) behind the inner ankle.

LIGATURE IN THE MIDDLE OF THE LEG

The limb is abducted and rotated outwards, the knee and hip are flexed, and the heel is made to rest on the instep of the opposite foot. The surgeon stands facing the inner aspect of the limb and makes an

FIG. 176. INCISIONS FOR EXPOSURE OF THE POSTERIOR TIBIAL ARTERY. The incisions are for exposure of the vessel in the middle and lower thirds of the leg and behind the inner ankle, in order from right to left.

incision four inches long parallel to and a finger's breadth behind the inner border of the tibia, the centre of the incision corresponding to the mid-point of the leg (see Fig. 176). The incision is deepened carefully in order to avoid the internal (great) saphenous vein and nerve which lie parallel to and often immediately under it. If seen, the vein must be drawn aside; if it cross the incision too obliquely it must be divided. The deep fascia is next opened up to the full extent of the wound, the inner border of the gastrocnemius is drawn downwards, and the characteristic fibrous aponeurosis of the soleus is exposed. The portion of this muscle arising from the tibia must now be divided throughout its whole thickness before the deep calf muscles can be exposed. The incision in the muscle is made about three-quarters of an inch from the inner border of the tibia, with the blade of the knife held horizontal and cutting directly towards the posterior surface of that bone. As the muscle is cut through, its fibres are pushed aside, and the white, glistening intermuscular aponeurosis comes into view. This is slit up for the whole length of the wound, and, after dividing a few more muscular fibres, the space between the superficial and deep muscles is opened up and the flexor digitorum longus is seen. The foot is now fully plantar-flexed and the knee a little more flexed in order to relax the calf muscles as much as possible, when the vessels will come into view lying upon the deep muscles and bound down by a special fascia which must be divided before they can be reached. The nerve lies to the outer side of the artery and is often not seen. The venæ comites had better be taken up with the artery. The needle is passed from the outer side.

Difficulties. There are several, unless the operation be done with great care. The first trouble may arise from a large gastrocnemius, especially if the calf muscles are not allowed to hang free, as, for instance, when the operation is attempted with the limb lying flat on the table, or with an assistant supporting the calf. The posterior surface of the gastrocnemius may then be exposed and mistaken for the soleus. The latter muscle can be recognized by the characteristic arrangement of the fibres of its posterior aponeurosis, which are arranged very obliquely to the long axis of the limb, while those of the gastrocnemius are parallel to it. Sometimes the gastrocnemius is cut through in mistake for the soleus. In this case the plantaris will be met with between the two muscles and will put the operator on the right track.

Another difficulty will be met with if the section of the muscular belly of the soleus be practised wrongly. If the knife be held with its blade nearly vertical instead of horizontal as it should be, the incision will travel downwards between the two aponeuroses of the soleus instead of across that muscle, and the deep muscles will not be reached.

Then again, the interval between the superficial and deep calf muscles may not be recognized, and the deep muscles may be detached from the tibia and retracted, and the vessels with them, until finally the operator arrives at the interosseous membrane. This mistake is easily obviated by taking care to recognize the intermuscular aponeurosis of the soleus when it is reached. The cellular interval in the calf is reached almost immediately after this has been divided. The artery is to be looked for lying behind the posterior surface of the tibia on the flexor digitorum longus, and not in the middle of the wound, where one is tempted to look for it.

LIGATURE IN THE LOWER THIRD OF THE LEG

The position of the limb and of the surgeon are the same as in the preceding operation. An incision two inches long is made parallel to and midway between the adjacent margins of the tibia and the tendo

Achillis (see Fig. 176); if the latter cannot be felt the incision should be half an inch behind the inner border of the tibia. The internal (great) saphenous vein must be avoided as before, and the deep fascia opened up throughout the whole length of the wound; the upper edge of the internal annular (laciniate) ligament may have to be divided below. This will expose the fascia binding down the deep flexor tendons, which must be divided and the tendons identified. The nearest to the edge of the tibia is the tibialis posticus (posterior), outside which comes the flexor digitorum longus. The cellular interval external to this tendon and between it and the flexor hallucis longus is now exposed without opening the tendon sheaths, and the artery is seen with its venæ comites and the large posterior tibial nerve lying external to it. The needle is passed from the outer side.

Difficulties. The only difficulty likely to arise is from the operator forgetting that the vessel lies on the deep muscles on the posterior surface of the tibia and bound down to them by a special fascia. It should, therefore, be looked for upon the anterior aspect of the wound, and not at the bottom of it, otherwise there is a risk of losing one's way in the fat in front of the tendo Achillis.

LIGATURE BEHIND THE INNER ANKLE

The knee is flexed and the limb laid on its outer side. The surgeon stands on the opposite side of the table, facing the inner aspect of the limb, and makes a crescentic incision with its concavity forwards a good finger's breadth behind the inner malleolus, nearly two inches in length, the greater part of the incision being parallel to its posterior border (see Fig. 176), as the artery should be secured above the point of the malleolus, where it is comparatively superficial. The incision must be deepened to the internal annular (laciniate) ligament, which is defined and incised carefully along the line of the original incision. This should lie almost over the vessels, which are situated in a definite cellular interval that can be felt just external or posterior to the tendon of the flexor digitorum longus and between it and that of the flexor hallucis longus. The first tendon felt beneath the malleolus is that of the tibialis posticus (posterior), next to that comes the flexor digitorum longus, then the interval for the vessels and nerve, and finally the tendon of the flexor hallucis longus; the tendon sheaths should not be opened. The nerve lies on the outer or fibular aspect of the vessels, and is of large size; the venæ comites may have to be taken up with the artery. The knife should be directed towards the malleolus as the incision is deepened, or else a deep dissection may be made backwards towards the heel.

CHAPTER VII

LIGATURE OF THE ARTERIES OF THE KNEE AND THIGH

LIGATURE OF THE POPLITEAL ARTERY

Indications. (i) *Punctured or gunshot wounds* involving the popliteal artery. These will require enlargement of the wound in the line of the artery, after a tourniquet has been applied round the thigh; when the bleeding point is found, the vessel must be secured between two ligatures. It will rarely be possible to suture the artery, even though there be only a small aperture in its walls owing to the deep situation of the vessel and the importance of the surrounding structures.

(ii) *Injury to the popliteal artery from dislocation, fracture of the femur, or direct crush.* In these cases the artery should be exposed near its origin by a median vertical incision over the upper part of the popliteal space, and traced down to the seat of injury, where a double ligature should be applied. A tourniquet will be required here also.

(iii) *Injury to the popliteal artery during osteotomy.* In these rare cases the artery should be exposed—after applying a tourniquet to the thigh—from the inner aspect of the thigh by the incision given below (see p. 437).

(iv) *Aneurysm.* Ligature of the popliteal artery for aneurysm may be practised for three different conditions:

(*a*) When the aneurysm springs from the lower part of the popliteal artery.

(*b*) When pulsation has recurred after ligature of the femoral in Hunter's canal for a popliteal aneurysm.

(*c*) When the surgeon desires to do the 'old' operation, as in cases of traumatic, ruptured, or inflamed aneurysm. It is, however, possible that further experience of Matas's operation for aneurysm may lead to a modification of the present treatment of this affection (see p. 382).

(v) *Wounds of the leg* in which it is uncertain whether the bleeding comes from the anterior or posterior tibial. In these cases the popliteal should be exposed at its termination and traced down until the source of bleeding has been identified and the bleeding ends secured.

Surgical anatomy. The popliteal artery extends from the lower border of the opening in the adductor magnus to the lower border of the popliteus muscle, where it divides into the two tibials. This point on the back of the limb corresponds to the lower part of the tubercle of the tibia in front. At first the artery runs somewhat outwards until it reaches the interval between the two condyles, when it descends vertically in the middle of the popliteal space.

The vessel is very deeply placed, being in contact *anteriorly* with the triangular surface of the femur, the posterior ligament of the knee-joint, and the fascia covering the popliteus muscle. *Posteriorly,* it is overlapped above by the semimembranosus, while below it is beneath the adjacent borders of the two heads of the gastrocnemius, especially the inner one. The popliteal vein and the internal popliteal (tibial) nerve both lie behind the artery about its middle, the vein being closely applied to the back of the vessel and separating it from the nerve, which crosses the artery obliquely from without inwards and from above downwards. Below, the vessel is crossed by the nerve to the popliteus, and also by the plantaris muscle when it exists. On its *outer side* lie the popliteal vein and the internal popliteal (tibial) nerve above, the outer condyle of the femur about its middle, and the outer head of the gastrocnemius and the plantaris below. On the *inner side* are the semimembranosus above, the inner condyle about the middle, and the nerve to the popliteus, the internal popliteal (tibial) nerve and the inner head of the gastrocnemius below.

The artery may be tied at its commencement or at its termination. It is hardly ever tied in the middle of its course, although this might have to be done in cases of rupture; the vessel here is very deep and intimately connected with the vein, so that the difficulty of isolating and tying it is great.

The vessel may be ligatured (*a*) from the inner aspect of the thigh, (*b*) in the upper part of the popliteal space from behind, (*c*) in the lower part of the popliteal space from behind.

LIGATURE FROM THE INNER ASPECT OF THE THIGH

The knee is flexed nearly to a right angle, and the limb is abducted and rotated outwards, being supported on the heel. No pillow or support should be placed beneath the knee, otherwise the hamstrings will be displaced. The surgeon stands facing the inner aspect of the limb; if he stands on the outer side of the limb it is impossible to get a good view. The adductor magnus tendon is first identified by abducting the limb forcibly, and the adductor tubercle into which it is inserted is also made out. An incision four inches long and parallel to, but a little below, the adductor tendon is then made from the junction of the lower with the middle third of the thigh downwards to just below the adductor tubercle (see Fig. 177). The internal (great) saphenous vein, which lies almost in the line of the incision, must be avoided. After division of the deep fascia the sartorius is seen, its anterior border is defined, and the muscle drawn downwards. The operator then feels for the adductor magnus tendon and cuts down on it. The free edge of this structure stands out as a rounded white cord, along the lower edge of which the knife is passed

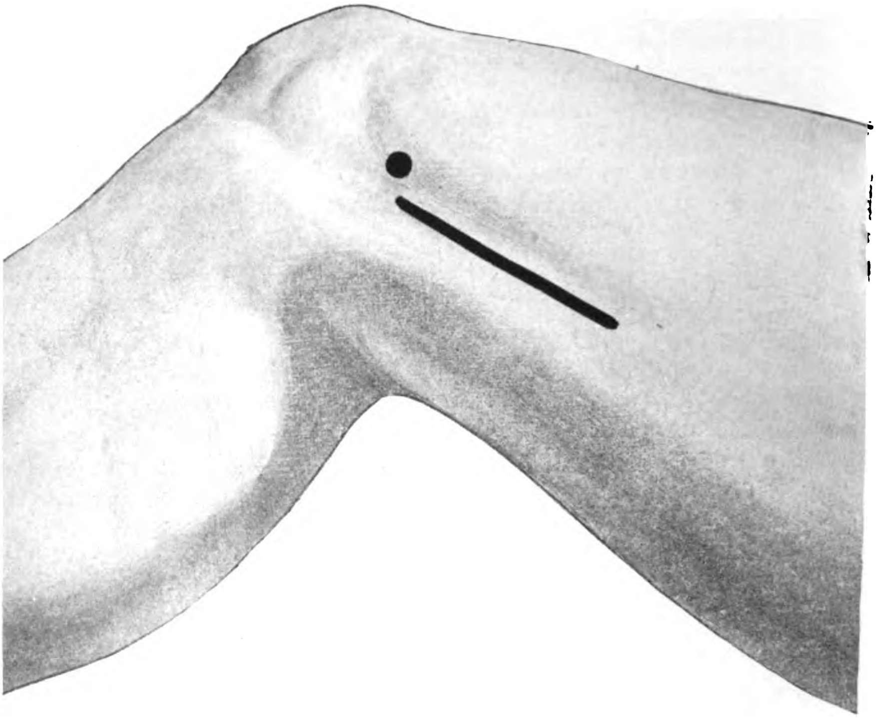


FIG. 177. INCISION FOR LIGATURE OF THE POPLITEAL ARTERY FROM THE INNER SIDE OF THE THIGH. The dot is placed upon the adductor tubercle.

so as to divide the fascia and allow the semimembranosus to be pulled downwards and the upper part of the popliteal space to be opened up. When this has been done, the finger, with the pulp directed upwards towards the triangular posterior surface of the femur, is passed into the areolar tissue of the popliteal space and the artery is felt beating between the bone and the finger. The knee is now flexed still more fully, so as to relax the parts as much as possible, and the surgeon opens the sheath of the artery from the inner side, clears the vessel and passes the aneurysm needle from the upper and outer aspect of the artery (see

Fig. 178). The vein and nerve lie to the outer side of the vessel and are not seen.

Difficulties and dangers. In the living subject the only difficulty met with is in opening the sheath and cleaning the artery in fat subjects. The artery lies very deep and can only be seen with difficulty. Good flexion of the knee, a forehead-light, a free incision and long-handled

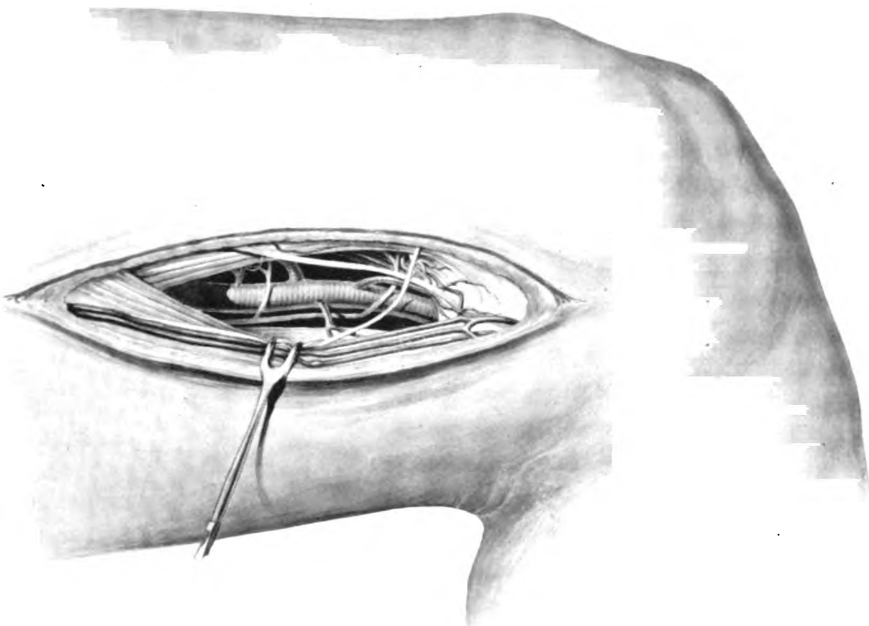


FIG. 178. THE POPLITEAL ARTERY FROM THE INNER SIDE OF THE THIGH. The hook is pulling down the sartorius and the internal (great) saphenous nerve is seen above. The lower border of the adductor tendon is visible above the artery.

instruments, including aneurysm needles of various curves, will overcome this difficulty. It is also essential that the surgeon should face his work; if he stands on the outer side of the limb, as is often recommended, his difficulties are greatly increased.

In the dead subject an additional difficulty may arise from inability to define the adductor tendon. A very common mistake, after the popliteal space has been opened, is to thrust the finger between the artery and the femur and push the former backwards into the popliteal space, where there may be great difficulty in identifying it. It should always be possible to feel the artery easily against the femur in the dead subject, as it is a large and usually a rigid one. It should be cleared carefully without dragging it from its bed, and great caution is necessary in passing the aneurysm needle for fear of puncturing the vein. Fig. 179 shows the intimate connexion between the two structures in this situation.

LIGATURE FROM THE BACK OF THE LEG

In the upper part of the popliteal space. As it is inconvenient to the anæsthetist to roll the patient fully over on to his face, it will be

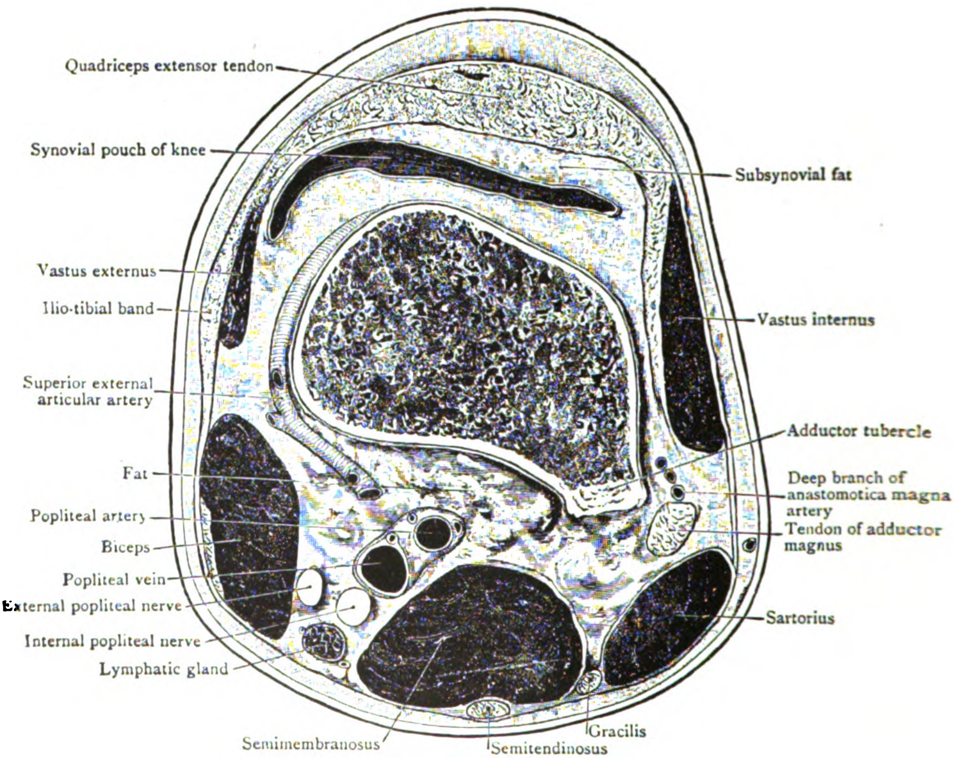


FIG. 179. SECTION THROUGH THE THIGH IMMEDIATELY ABOVE THE PATELLA (Cunningham's *Anatomy*).

sufficient to turn him well over on to the affected side, flexing the sound leg upon the trunk so as to prevent him from assuming the completely prone position.

The surgeon stands on the outer side of the limb and feels for the outer border of the semimembranosus. An incision four inches long is made along this structure down to the transverse popliteal crease seen on the skin at the back of the knee. When the superficial structures have been divided, the outer edge of the semimembranosus comes into view and is cleared and pulled inwards, when the pulsations of the artery can be felt in the upper part of the popliteal space. In doing this the lesser sciatic (posterior femoral cutaneous) nerve will probably be seen and should be avoided. Large retractors are inserted into the wound, and the internal popliteal (tibial) nerve at once comes into view, hiding the artery, which lies to its inner side and on a deeper plane, with the vein interposed between it and the nerve; the latter structure should be drawn to the outer side with a retractor, the vein with it. The sheath of the artery is then opened from its inner side, and the vessel cleared. The needle should be passed between the vein and the artery, namely, from the outer side first. It is fairly easy to get at the artery in this position, certainly easier than in the preceding operation, but great care should be taken to avoid damaging the vein, which almost entirely conceals the artery and is closely connected with it. There is also occasionally troublesome bleeding from the small articular vessels in this situation.

Fig. 180. Incision for Exposure of the Popliteal Artery in the Lower Part of the Popliteal Space. The white line indicates the incision.

In the lower part of the popliteal space. The limb is in the same position as before, and the surgeon stands on the outer side. A vertical incision about three inches and a half long is made in the middle line of the popliteal space commencing about the level of the knee-joint, viz. one inch below the transverse crease usually seen at the back of the limb (see Fig. 180). If there be any difficulty in identifying this crease, the level of the knee-joint may be made out by inserting a finger deeply into the popliteal space and then flexing and extending the knee.

As the incision is deepened, the external saphenous (sural) nerve or the tibial communicating (medial sural cutaneous) nerve will be met with and must be avoided. The deep fascia is then opened up throughout the whole of the wound, and the heads of the gastrocnemius muscle are identified, and their line of union made out by the direction of the muscular fibres. The two heads of the muscle are then separated widely and the division between them is prolonged downwards, if necessary, through the muscular fibres for about an inch and a half to two inches. In doing this the operator will probably come across the sural vessels and the plantaris muscle, which should be drawn aside. The next structure that comes into view is the internal popliteal (tibial) nerve which lies here on the inner side of the vein, and superficial to it. These structures are pulled over to the inner side with a blunt hook, without attempting to separate them (see Fig. 181). The artery can then be felt pulsating beneath them, and its sheath is opened well to the outer side, the vessel cleared, and the needle passed from the outer side, that is to say, between the vein and the artery.

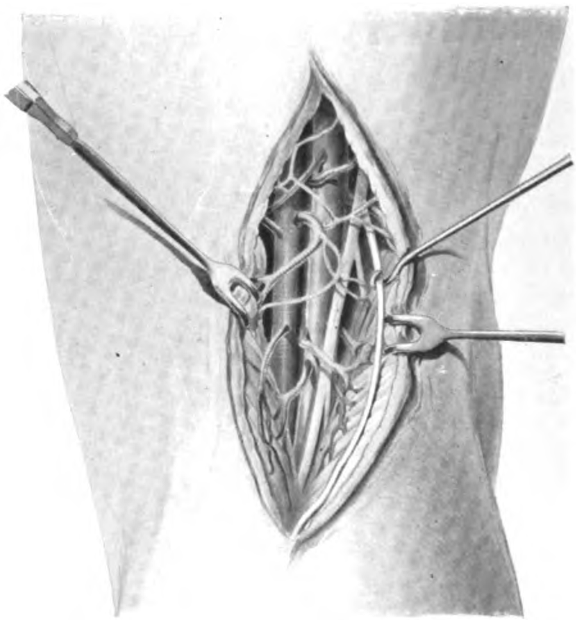


FIG. 181. THE POPLITEAL ARTERY IN THE LOWER PART OF THE LEFT POPLITEAL SPACE. The heads of the gastrocnemius have been separated for some distance and hooked aside. The relations of the nerve, vein, and artery are well seen. The nerve under the small hook is the tibial communicating (medial sural cutaneous).

Difficulties and dangers. The chief risk of the operation is the liability to wound the vein, which is best avoided by retracting it together with the internal popliteal (tibial) nerve to the inner side as directed above. The vessel should be secured well below the level of the junction of the two heads of the gastrocnemius muscle, and the depth at which the vessel lies may cause some difficulty in passing the needle; should this be the case, the knee must be fully flexed to relax the muscles.

The wound is sutured without a drainage tube, and the limb is put up on a straight back-splint with a small pad between it and the popliteal space. This will obliterate the cavity in the popliteal space sufficiently.

LIGATURE OF THE FEMORAL ARTERY

Indications. (i) *Wounds of the femoral artery.* In these cases the vessel must be exposed at the seat of injury and appropriate treatment employed, after the circulation has been commanded above the wound, either by a tourniquet or by digital pressure. Since arteriorrhaphy has come within the sphere of practical surgery there is little doubt that some of these cases will fall within its scope, especially when the wound

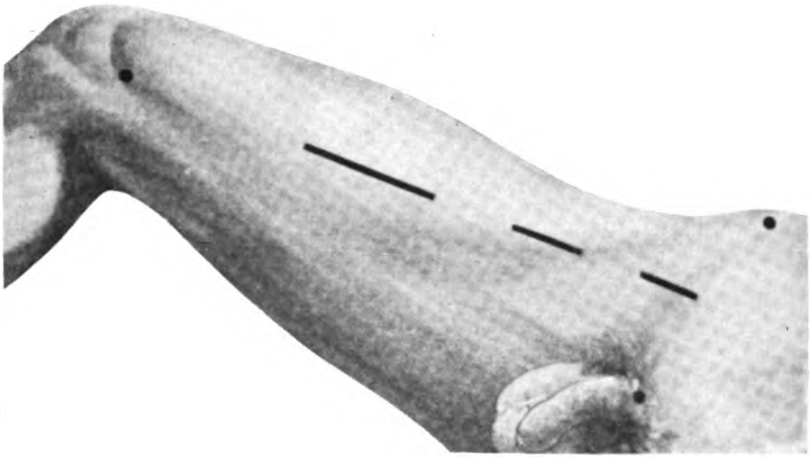


FIG. 182. INCISIONS FOR LIGATURE OF THE FEMORAL ARTERY. The two dots on the right-hand side are upon the anterior superior iliac spine and the symphysis pubis respectively; that on the left is over the adductor tubercle. The incisions are, from left to right, for ligature of the vessel in Hunter's canal, at the apex of Scarpa's triangle, and below Poupart's ligament (common femoral).

is small and situated where the vessel is large; this is referred to again in connexion with ligature of the common femoral (see p. 450).

When no attempt to suture the wound in the vessel wall is deemed feasible or advisable, the vessel should be secured by ligature above and below the wound in its wall, and it will be a good plan to divide the vessel completely between the ligatures, as this allows retraction of the ends and complete protection against secondary hæmorrhage.

(ii) *Aneurysm.* The spot at which the vessel should be secured will vary according to the situation of the aneurysm; thus, for an aneurysm in the popliteal space the artery may be tied either in Hunter's (the adductor) canal, or at the apex of Scarpa's triangle (the femoral trigone); for an aneurysm of the superficial femoral the artery might be tied at the apex of Scarpa's triangle (the femoral trigone); more probably, however, the common femoral artery would have to be tied.

FIG. 183. LINE OF THE FEMORAL ARTERY WHEN THE LOWER EXTREMITY IS FULLY EXTENDED. The upper × is on the mid-point between the anterior superior iliac spine and the symphysis pubis, the lower on the inner border of the patella.

(iii) In *aneurysmal varix* at the groin the common or the superficial femoral artery may require ligature. In such a case as this, however, the best operation would be to secure the femoral between double ligatures on each side of the communication, and then to divide the vessel between the double ligatures, thus leaving the circulation through the vein unimpaired; or it might be possible to expose the connexion between the two vessels and suture each orifice separately (see p. 395).

(iv) Ligature of the femoral may be necessary in *the removal of large growths* from Scarpa's triangle. As a rule, however, it will be sufficient to expose the common femoral trunk and apply a temporary ligature or a Crile's clamp (see Fig. 155) to it. This matter is more fully referred to in connexion with ligature of the common femoral artery (see p. 450).

Surgical anatomy. The femoral artery is the direct continuation of the external iliac; it extends from the lower border of Poupart's ligament to the tendinous opening in the adductor magnus. Its course is indicated by a line drawn from the mid-point between the anterior superior spine of the ilium and the symphysis pubis to the adductor tubercle when the knee is slightly flexed and the thigh rotated outwards (see Fig. 182). When the limb lies flat on the table, and is parallel to its fellow, however, the line of the artery is materially altered—a point of great importance when tying the vessel in the rigid dissecting-room subjects prepared by the formalin method. In this case the line should be taken to the inner border of the patella instead of to the adductor tubercle (see Fig. 183). In the upper half of its course the artery lies in Scarpa's triangle (the femoral trigone), and is superficial. In the lower half, however, it is more deeply placed and lies in Hunter's (the adductor) canal. At its commencement the artery lies in a funnel-shaped process of the fascia called the femoral sheath, which is divided by septa into three compartments, the outer one containing the artery and the crural (lumbo-inguinal) branch of the genito-crural (genito-femoral) nerve, the middle one the femoral vein, and the most internal, called the crural canal, containing lymphatics and lymphatic glands. The first inch

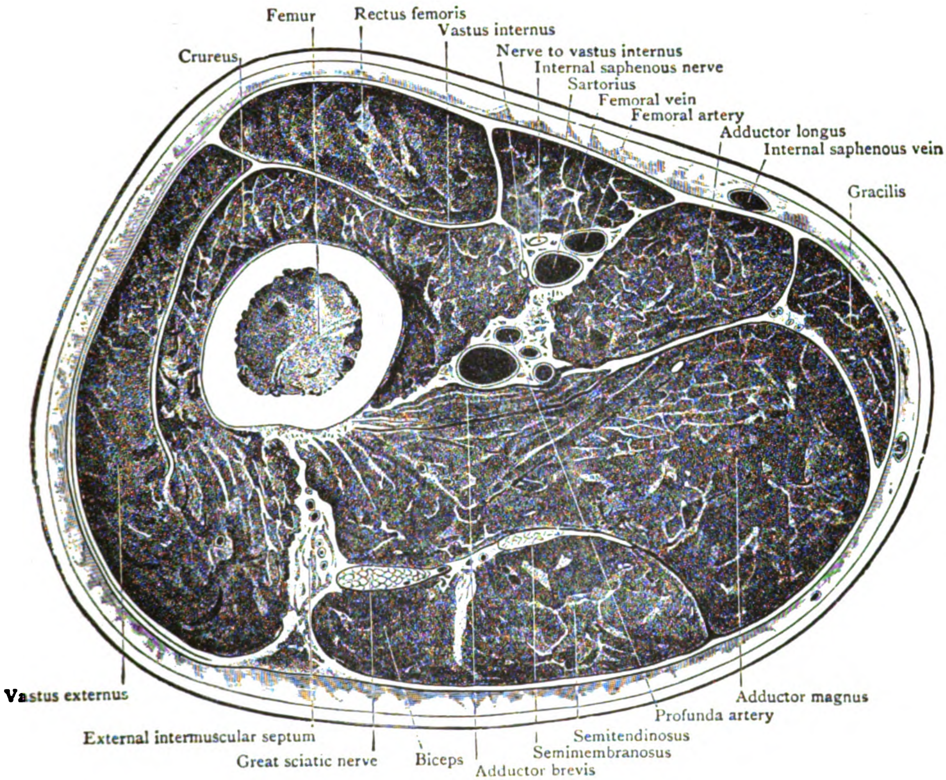


FIG. 184. SECTION THROUGH THE THIGH AT THE LEVEL OF THE UPPER PART OF HUNTER'S CANAL (Cunningham's *Anatomy*).

and a half to two inches of the vessel is known as the common femoral, the rest being termed the superficial femoral.

In front the artery is covered by the skin and superficial fascia, in which are the superficial inguinal glands, and the superficial circumflex iliac vein crosses it. It is also covered by the anterior part of the femoral sheath, the iliac portion of the fascia lata, the cribriform fascia, and, below this, by the deep fascia of the thigh. Near the apex of Scarpa's triangle (the femoral trigone) it is crossed by a cutaneous branch of the anterior crural (femoral) nerve and a branch of the internal (great) saphenous vein. The crural (lumbo-inguinal) branch of the genito-crural (genito-femoral) nerve is in front and to the outer side of the artery above, and runs for some distance within the femoral sheath.

In Hunter's (the adductor) canal (see Fig. 184) the vessel is covered by a special fascia forming the roof of the canal; superficial to this is the sartorius muscle with the skin, superficial and deep fasciæ. The internal or long saphenous nerve lies at first to the outer side of the artery in the canal, then it crosses in front of it, and finally descends upon its inner side.

Behind, the artery is in relation from above downwards with the posterior part of the femoral sheath, the pubic portion of the fascia lata, the psoas, pectineus, and the upper part of the adductor longus muscle; while in Hunter's (the adductor) canal it lies in the angle between the vastus internus (medialis) and the adductors. The nerve to the pectineus passes between the artery and the psoas muscle, while the femoral vein and the profunda artery and vein intervene between it and the pectineus. The femoral vein also separates it from the adductor longus.

Laterally, the femoral vein lies to the inner side of the artery above, at the apex of Scarpa's triangle (the femoral trigone) it passes behind it, and in Hunter's (the adductor) canal it is posterior and to some extent external to it. On the outer side of the artery above is the anterior crural (femoral) nerve, but this structure is separated from it by nearly half an inch. Lower down, the saphenous nerve crosses the artery obliquely in Hunter's (the adductor) canal from the outer to the inner side, and the nerve to the vastus internus (medialis) is on its outer side.

The artery may be tied in three situations: (i) in Hunter's (the adductor) canal, (ii) at the apex of Scarpa's triangle (the femoral trigone), (iii) above the origin of the superficial femoral.

LIGATURE IN HUNTER'S CANAL

The surgeon stands on the outer side and has the knee flexed and the thigh somewhat abducted and rotated outwards. An easy way to maintain this position is to place the foot of the affected side upon the opposite instep and to support the knee on a suitable sand-bag. The line of the artery (*vide supra*) is marked out, and the surgeon makes an incision about three inches long in the line of the vessel, with its centre opposite the middle of the thigh (see Fig. 182). As the wound is deepened the internal (great) saphenous vein will probably be encountered and should be drawn aside, or divided between ligatures if this be impossible. The deep fascia is then incised throughout the length of the wound, and the sartorius comes into view. This muscle is identified by the direction of its fibres, which run vertically downwards. The outer border of the muscle is defined and drawn inwards or downwards with a retractor. This exposes the roof of Hunter's (the adductor) canal, which can nearly always be distinguished by the transverse direction of its fibres, and through which the pulsations of the artery can be felt in the living subject (see Fig. 185). The roof of the canal is now opened throughout the length of the wound, and the artery comes into view with the saphenous nerve crossing it from without inwards. The nerve to the vastus internus (medialis) lies some distance to the outer side of the vessel and is not

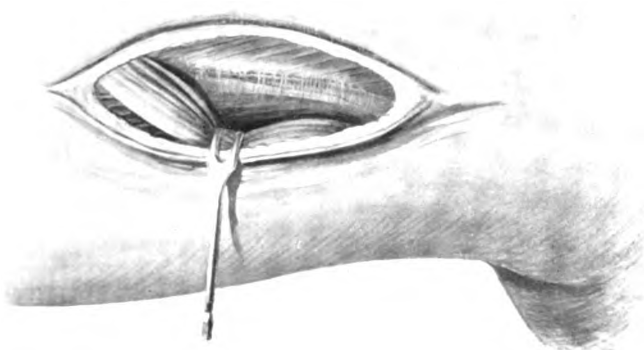


FIG. 185. LIGATURE OF THE FEMORAL ARTERY IN HUNTER'S CANAL. The sartorius is pulled down by the retractor, exposing the vastus internus (medialis) fibres and the aponeurotic roof of Hunter's canal, through which can be seen the artery with the long saphenous nerve crossing it obliquely from without inwards.

seen if the incision has been accurately made. The sheath is opened, the vessel cleared, and the aneurysm needle passed in the usual way, and in whatever direction is easiest, care being taken to keep it closely in contact with the posterior aspect of the artery, as the vein lies behind.

Difficulties and dangers. The chief difficulty in the operation comes from taking an incorrect line for the artery, so that the incision is made too far internally, and the surgeon looks for the vessels on the muscles on the inner side of the thigh. If this be done a deep dissection may be made without any chance of finding the vessel. It is very important to remember that the limb should be rotated outwards and moderately abducted before the incision is made; if this cannot be done owing to rigidity of the limb, the alternative line given above (see p. 444) should be used and will help to avoid confusion. The vein lies behind the artery and is not seen, but it may be wounded by the aneurysm needle unless care be taken to keep the point of the latter in close contact with the vessel wall as it is passed around its posterior aspect. Fig. 186 gives a clear view of the relations of the structures in this region.

LIGATURE AT THE APEX OF SCARPA'S TRIANGLE

The limb should be in the same position as for the preceding operation (*vide supra*), and the surgeon, standing on the outer side of the limb,

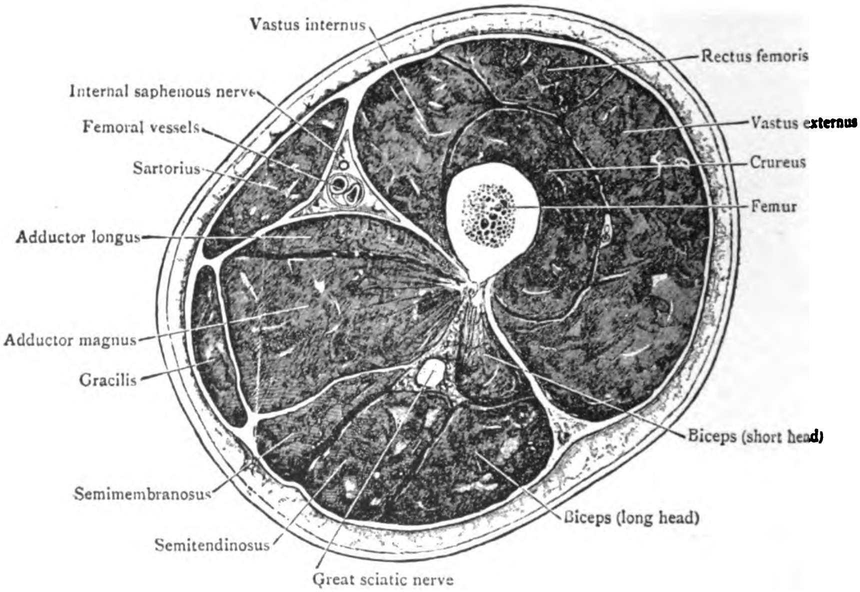


FIG. 186. TRANSVERSE SECTION THROUGH THE THIGH (HUNTER'S CANAL) (Cunningham's *Anatomy*).

makes an incision about two inches long in the line of the artery (see p. 444), commencing about four inches below Poupart's ligament. The skin and fascia are divided throughout the whole length of the wound—dividing the veins going to join the saphenous—when the sartorius comes into view, and is identified by the direction of its fibres, which run obliquely downwards and inwards. The inner border of this muscle is defined and drawn outwards with a retractor, and the artery will then be felt pulsating immediately beneath the muscle at the lower end of the wound. The femoral sheath is opened well to the outer side, taking care in doing so to avoid damage to the crural (lumbo-inguinal) branch of the genito-crural (genito-femoral) nerve. The artery is carefully cleared, and the needle is passed from within outwards; it must be kept very close to the artery in the first part of its course, so as to avoid the vein which lies to the inner side, and somewhat behind the artery. When the ligature is tightened, the middle and internal coats of the vessel should be divided.

Difficulties and dangers. Wound of the femoral vein is not a very uncommon accident and generally results from clumsy attempts to clear the artery. Unless the sheath be adequately opened before the

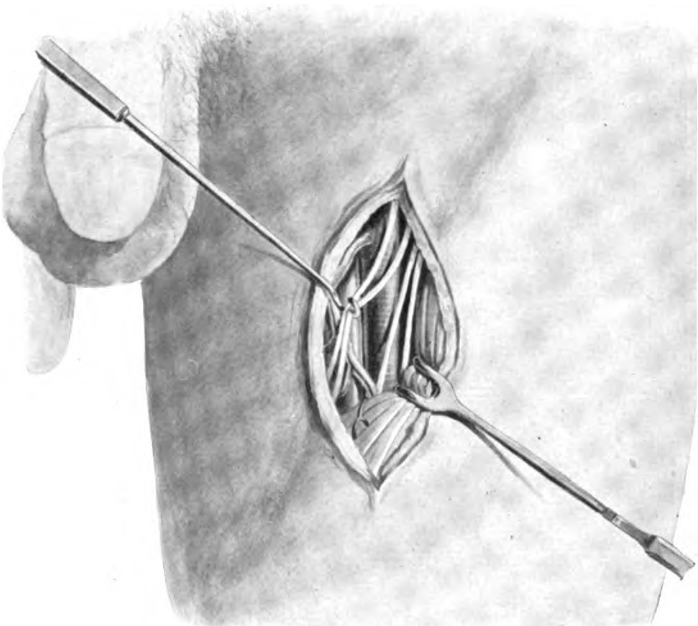


FIG. 187. LIGATURE OF THE SUPERFICIAL FEMORAL AT THE APEX OF SCARPA'S TRIANGLE. The sartorius is pulled outwards by the retractor. The small nerves in the hook are cutaneous branches from the anterior crural.

needle is insinuated round the vessel, its point is apt to be forced through the wall of the vein. Should such an accident occur, pressure should be applied to the vein on both sides of the injured spot and a lateral ligature applied. The artery should then be cleared at a fresh spot lower down and tied.

The internal (great) saphenous vein may be exposed and wounded; if so, it should be tied. This accident is not of the least consequence in an aseptic wound and does not give rise to œdema unless sepsis occurs.

No other accidents are likely to occur, as the artery is superficial and easily found, and the various nerves in the vicinity are some little distance from the vessel.

Before the operation, the whole lower extremity should be scrupulously purified and wrapped up in sterilized cotton wool. After the operation, the limb should be elevated in bed on a firm pillow with a stout ring pad beneath the heel and a cradle over the limb, so as to minimize the risk of gangrene. In all cases of ligature of the femoral artery the patient must be kept in bed for at least three weeks after the operation. When this has been done for aneurysm another three or four weeks must be allowed for proper consolidation to occur in the sac.

LIGATURE BELOW POUPART'S LIGAMENT (THE COMMON FEMORAL)

This operation is comparatively often done and may be required:

Indications. (i) For a *wound of the artery* or for one of the sequelæ of a wound, such as a *traumatic aneurysm* or an *aneurysmal varix*. The wounds of this vessel that the surgeon is likely to be called upon to treat are either punctured wounds of the groin, where the damage to the artery is small enough to allow of its being stopped by pressure before the hæmorrhage is fatal, or, more commonly, an injury to the vessel occurring during an operation such as removal of large tumours from the groin.

Ligature of the artery need not necessarily be performed for simple wounds that do not involve loss of a portion of the vessel wall, as it is here that arteriorrhaphy should find one of its most useful applications, since it is easy to control the circulation above and below the wound, and the size of the artery allows of easy manipulation and suture of the vessel wall without materially interfering with its lumen. Even complete division of the vessel may be treated by end-to-end suture provided that no portion of the artery be actually removed; the loss of a portion would probably prevent end-to-end union owing to the difficulty of getting the divided ends into apposition. When, however, large growths or malignant glands are being removed from the groin, portions of the artery and the vein may be removed with them either accidentally or designedly. The vein more often requires removal than the artery, as its sheath is in close proximity to the glands and soon becomes infiltrated, in which case it is much sounder surgery to remove the glands with the requisite portion of the vein than to dissect the glands off the wall of the vein, a procedure which is very liable to end in recurrence. Removal of a portion of the common femoral vein presents no risks provided that the wound be aseptic, nor need the surgeon hesitate to remove a portion of the common femoral artery also should occasion demand it.

That complete removal of the main artery and vein of the limb from the external iliac to the profunda does not necessarily cause gangrene was proved by the case shown by Mr. C. H. Fagge at the Royal Society of Medicine, May 8, 1908, in which the right external iliac artery was exposed and trebly ligatured with catgut, the lowest ligature being an inch and a half above Poupart's ligament. The deep epigastric was tied, the incision prolonged downwards, and the superficial femoral ligatured, as was also the deep femoral branch. The circumflex iliac vessels were similarly treated, and the corresponding veins were tied so that the whole mass could be removed. The thigh and leg presented a mottled appearance for forty-eight hours, after which pulsation returned, but the pulse in the operation area could not be felt for a month afterwards. Superficial gangrene appeared in the region of the wound, and a small blister formed on the heel.

In cases of *aneurysmal varix* it will hardly ever be necessary to tie the common femoral, since the circulation can be controlled effectually on both sides of the communication by a temporary ligature, after which an attempt may be made to separate the union between the vein and the artery and to repair the opening in each of these structures by appropriate plastic methods (see p. 395). Failing this, the best plan will be to secure the artery on either side of the anastomosis, and then to suture the opening in the vein so as not to impair the circulation through it.

(ii) Ligature of the common femoral has been only rarely performed for the cure of an *aneurysm of the superficial femoral,* as in the past the majority of surgeons were in favour of applying a ligature to the external iliac instead. The reasons given for this were that the collateral circulation in the neighbourhood of the ligature on the common femoral is so free that proper consolidation is not likely to occur in the aneurysm, and that the length of the common femoral is so variable that it is easy to tie the superficial branch in mistake for the common trunk. An argument that formerly weighed considerably against the operation was the risk of gangrene, which appears to have been much greater when the common femoral was tied than when the ligature was put on the external iliac.

This, however, was associated with sepsis and is not now to be feared. The arguments adduced above do not appear to rest upon any sound basis, and excellent results have been obtained by the ligature of the common femoral. I should not hesitate to make use of it for aneurysm high up on the superficial femoral in a suitable case, although it is probable that Matas's operation will largely take its place in the future.

Operation. The groin is shaved, the limb is put into a position similar to that for the preceding operation (see p. 446), and the line of the artery (see p. 444) marked out as before. It is important to identify Poupart's ligament accurately, which is often difficult in the dead body but easy in the living subject. An incision two inches long is made in the line of the artery with its centre over Poupart's ligament, and the superficial structures are divided until that structure is reached. Several glands and small vessels are met with and must be dealt with as may be

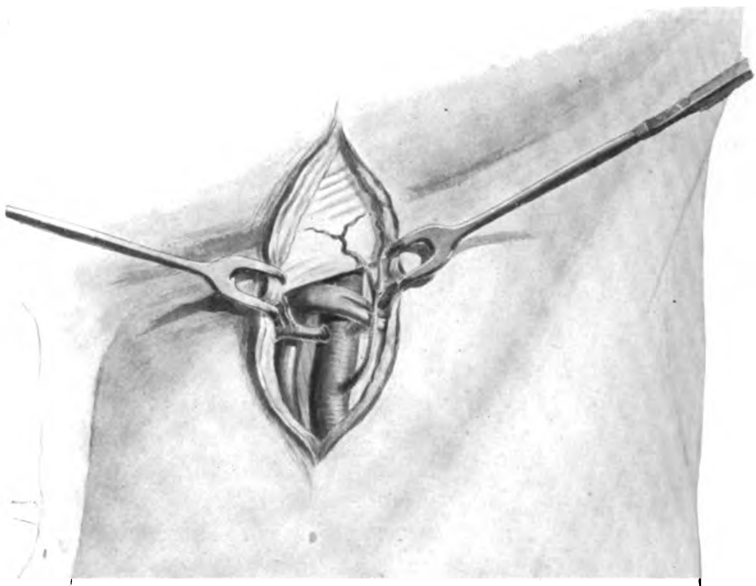


FIG. 188. LIGATURE OF THE COMMON FEMORAL BENEATH POUPART'S LIGAMENT.

necessary. The deep fascia of the thigh is opened immediately below Poupart's ligament by a vertical incision, when the artery can be felt at once. The femoral sheath is opened well to its outer side and the artery is cleared (see Fig. 188). The needle is passed from within outwards, and care must be taken to keep it in close contact with the vessel so as to avoid taking in the crural (lumbo-inguinal) branch of the genito-crural (genito-femoral) nerve which lies upon the front of its sheath. In tying the ligature it will be well to make use of the stay-knot (see p. 420), and not to divide the inner and middle coats of the vessel. The wound is closed without a drainage tube: the treatment of the limb is the same as in the preceding operation (see p. 450).

The *after-treatment* is the same as for the previous case.

Difficulties and dangers. The chief difficulty is the uncertainty as to whether the common trunk or the superficial branch has been secured. It is not uncommon to find the common femoral exceedingly short; it is rarely more than one and a half inches long, and on occasions it may be almost absent. Under these circumstances the surgeon mistakes the superficial femoral for the common trunk. This mistake is very common in operations upon the dead subject, and is best avoided by making sure that the point at which the artery is tied is immediately under Poupart's ligament; the further away from it the ligature is placed, the greater is the likelihood of mistake.

CHAPTER VIII

LIGATURE OF THE ARTERIES OF THE PELVIS

LIGATURE OF THE EXTERNAL ILIAC ARTERY

Indications. (i) This artery is rarely tied; almost the only condition that calls for ligature of it is a *femoral aneurysm* high enough up to preclude ligature of either the superficial or the common femoral trunk.

(ii) For *wounds of the external iliac* it is not likely to be practised frequently. Wounds of that vessel are rare, and the few cases that survive that injury long enough to come under the hands of the surgeon will be more appropriately treated by some form of arteriorrhaphy (see p. 377). The external iliac artery is so large that suture of a wound in its walls should be a matter of comparative simplicity. It can be exposed by either of the methods given below, the circulation temporarily arrested by clamps or temporary ligatures applied on both sides of the wound, and the latter sutured. Even complete division of the artery—which as a non-fatal event would only be likely to occur during the course of a surgical operation—would be better treated by an end-to-end circular arteriorrhaphy (see p. 381) than by ligature.

(iii) Ligature of the external iliac artery was formerly a recognized method of treatment for *elephantiasis,* but this has been given up; it is useless and not devoid of risk.

Surgical anatomy. This artery is the larger of the two terminal divisions of the common iliac trunk, and extends from the side of the lumbo-sacral articulation to Poupart's ligament. The anatomical line of the artery is from a point three-quarters of an inch below and a little to the left of the umbilicus, to another point midway between the anterior superior spine of the ilium and the symphysis pubis; the former point lies on the level of a line joining the highest parts of the crests of the ilia. The lower two-thirds of this line denote the external iliac vessel. The artery varies in length, but usually is about three and a half inches long.

In front of the artery are the peritoneum, and on the right side the terminal portion of the ileum and occasionally the appendix, while on the left side are the sigmoid flexure and some coils of small intestine. The ureter may cross the artery near its origin; the ovarian vessels also cross it in the female, and the spermatic in the male, the former near its origin, the latter near its termination. Near its termination also, the genital (external spermatic) branch of the genito-crural (genito-femoral) nerve and the deep circumflex iliac vein are in front of the vessel, while the vas deferens in the male and the round ligament in the female curve over it to enter the pelvis; numerous lymphatic vessels lie in front of the vessel throughout its whole length.

Behind, the artery lies upon the iliac fascia, from which it is separated by the external iliac vein above, and the psoas muscle and its tendon lower down; near its commencement the obturator nerve lies behind the artery.

Laterally, the genito-crural (genito-femoral) nerve lies to its outer side, while internally and somewhat more deeply placed is the external iliac vein. This aspect of the vessel is covered by peritoneum and is crossed by the vas deferens in the male and the ovarian vessels in the female.

Operation. The vessel may be reached by two routes, namely the *extra-peritoneal* or the *trans-peritoneal.* Of these the former is better suited for those cases in which the ligature has to be applied to the lower end of the artery, whilst the trans-peritoneal method is generally reserved for those in which the ligature must be applied high up, or may even have to be put round the common iliac trunk. Trans-peritoneal exposure of the artery, as will be seen from a perusal of the steps of the operation, is a very simple method, and it affords ample access to the great vessels, from the bifurcation of the aorta downwards, in a way that none of the other operations do. Now that trans-peritoneal operations have been robbed of their risk of sepsis, and especially since the introduction of the Trendelenburg position, the abdomen should be opened in all cases except those in which it is certain that the surgeon will have to deal with the extreme lower end of the vessel only. For these, Sir Astley Cooper's extra-peritoneal method is all that is required. It allows easier access to the vessel than does the trans-peritoneal method, in which the deep epigastric artery gets seriously in the way when the lower end of the vessel has to be exposed; at the same time there is no weakness left in the abdominal wall after it.

THE EXTRA-PERITONEAL OPERATION

Two operations are usually given in books for extra-peritoneal exposure of this vessel, called respectively by the names of Sir Astley Cooper and John Abernethy. Of these Sir A. Cooper's operation is probably the only one that would be done at the present day, and is well suited for reaching the artery at the lower end of its course with the least displacement of parts or liability to subsequent weakening of the abdominal wall. Abernethy's operation, on the contrary, does more damage to the abdominal wall, and is apt to leave it permanently weakened; it is more adapted for the application of a ligature high up on the external iliac artery, or on the common trunk, and, as this object is better attained by the trans-peritoneal method, Abernethy's operation will not be described here.

Sir Astley Cooper's operation. The bowels should be well cleared out before operation, and the pubic region shaved. An incision from three and a half to five inches long, according to the thickness

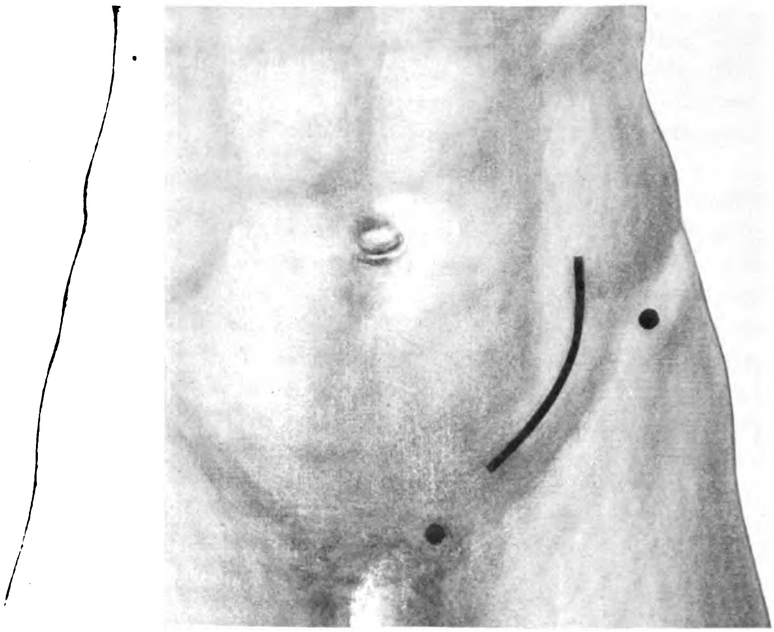


Fig. 189. Sir Astley Cooper's Incision for Extra-peritoneal Ligature of the External Iliac Artery. The right-hand dot is over the anterior superior iliac spine, the left-hand one over the spine of the pubes.

of the subcutaneous fat, is commenced at a point an inch and a quarter outside the pubic spine, and three-eighths of an inch above Poupart's ligament. The first two-thirds of this incision run parallel to Poupart's ligament, and then the incision curves upwards and inwards until it terminates an inch above and internal to the anterior superior spine of the ilium (see Fig. 189). In this incision numerous superficial vessels (*e.g.* superficial epigastric and circumflex iliac) are divided and will require ligature. When the incision has been deepened down to the external oblique aponeurosis, that structure is carefully slit up in the direction of its fibres throughout the whole length of the incision, and the fleshy fibres of the internal oblique muscle are identified below it. These in turn are divided to a similar extent and carefully differentiated from the arched fibres of the transversalis muscle a little deeper; at this stage the upper end of the internal abdominal ring will come into view. The fibres of the transversalis muscle are next cut through in the line of the wound, exposing the transversalis fascia; in the living subject there is usually a definite layer of cellular tissue between these two structures. The transversalis fascia is similarly divided throughout the extent of the wound and the extra-peritoneal fat and cellular tissue exposed. This stage of the operation requires to be done with great care, as the peritoneum may be mistaken for the transversalis fascia and opened by mistake.

When the transversalis fascia has been divided, the fingers are inserted into the wound, and the peritoneum is gently stripped upwards and inwards from the iliac fossa towards the umbilicus, carrying with it the intestines contained inside it. This is done with the fingers, as there is then less risk of damaging the membrane, and it must be effected with gentleness; if force be employed, the iliac fascia may be separated from the psoas muscle, and the vessels stripped up and carried with it. When the peritoneum has been separated sufficiently widely, a large retractor is inserted so as to pull it and the intestines up towards the umbilicus, and a good view can be then obtained, especially if a forehead-lamp be used. The external iliac artery will be felt running along the brim of the pelvis near the inner end of the wound, and its sheath should be opened well on the outer side, so as to avoid the vein which lies to its inner side. The genito-crural (genito-femoral) nerve must also be avoided both in clearing the sheath and in passing the ligature, which should be done from the inner side; the simplest plan is to hold the nerve aside with a small hook.

It is usual to tie the artery about an inch and a half above Poupart's ligament, so as to be above the origin of the deep epigastric branch which comes off the parent trunk quite close to the ligament. The ligature should only be tied tight enough to approximate the coats of the vessel and not to divide them; for this purpose the 'stay-knot' (see p. 420) is excellent.

After the bleeding has been arrested, the cut edges of each individual muscle are approximated by sutures of moderately stout catgut, and the wound is closed without a drainage tube. It is important, both for the proper approximation of the parts and the relief of tension on the divided abdominal muscles, that the patient should be propped up after the operation, and a large pillow placed under the knees so as to relax the abdominal wall as fully as possible. The precautions already indicated (see p. 450) are taken to avoid the occurrence of gangrene.

Difficulties and dangers. The difficulties of this operation are greater in the dead subject than in the living, in whom the differentiation between the various muscular planes of the abdominal wall is quite well marked. In the dead subject, especially in old and emaciated persons, it is easy to mistake the peritoneum for the transversalis fascia and to open the former by mistake. In the living subject, however, this mistake is not likely to occur unless the incision be begun too high above Poupart's ligament, in which case the well-marked cellular interval, which is always present between the fascia transversalis and the point at which the peritoneum becomes reflected from the abdominal wall on to the iliac fossa, is missed. Should such an accident happen, however, it would have but slight importance at the present day, since the operation could be completed quite satisfactorily either after sewing up the rent in the peritoneum or by enlarging the incision in it and completing the operation through the peritoneum.

The chief difficulty both in the living and the dead subject will be found in too short an incision. It is of great importance to calculate the length of the incision carefully, and to make all the incisions in the deeper parts the same length as that in the skin. The danger of detaching the artery from the psoas muscle has already been referred to; this accident, however, can hardly happen except as the result of using considerable force. Injury to the vein or to the genito-crural nerve may occur, but is easily avoided by care in clearing the vessel. The operator is usually warned not to open the internal ring, but this is a matter of very little importance, as it is easily sewn up subsequently. A more important thing is damage to the cord, which may occur if the incision be placed too low.

Jacobson and Rowlands (*The Operations of Surgery,* Fifth Edition, vol. ii, p. 7) mention a method of performing this operation by splitting the fibres of the abdominal muscles in the same manner as is done in the appendix operation. They claim for it that 'the risk of ventral hernia is greatly diminished, and the difficulties of the operation are not materially increased, if good retractors be used'. It is difficult to see why the ordinary operation should be accompanied by any risk of ventral hernia if the wound be kept clean and no drainage tube be used. Indeed, as far as the muscular incisions are concerned they correspond fairly closely to certain forms of operation for the radical cure of hernia. Any one who has tried the two methods will agree, I think, that it impedes the operator to split the muscles, and that in a fat subject it would be almost impossible to expose the artery thus if an aneurysm were present. Moreover, there is likely to be troublesome bleeding from large branches of the deep epigastric.

THE TRANS-PERITONEAL OPERATION

For reasons already mentioned (see p. 455) this method offers decided advantages over the preceding one, as it enables the surgeon to apply the ligature to any part of the vessel that may seem desirable; or he can, if he thinks fit, secure the common iliac trunk or the internal iliac branch through the same incision. The risks attaching to this operation have been very largely diminished at the present day, owing to the adoption of the Trendelenburg position; thanks to it, the field of operation is never obscured and the operation is greatly simplified.

A very useful incision is one about an inch to the mesial side of the linea semilunaris, from about half an inch above Poupart's ligament to the level of, or well above, the umbilicus, according to the fatness of the patient. The anterior layer of the sheath of the rectus is first divided, and then the outer edge of the rectus is defined and the muscle pulled inwards towards the middle line. The deep epigastric vessels must not be wounded in doing this, as very troublesome bleeding may occur if they are. The posterior layer of the sheath and the peritoneum are then opened in the line of the original skin incision, the patient is put in the Trendelenburg position, and the intestines are packed well out of the way in the upper half of the abdomen by means of a large abdominal cloth. The edges of the wound are held wide apart with broad flat retractors, and, if necessary, a forehead lamp is used to illuminate the field of operation.

The next steps of the operation vary somewhat according to whether the artery to be tied is on the left or the right side. On the left side the artery is covered by the meso-rectum, which has to be divided before the vessel can be reached. The common iliac and the upper part of the external trunk are covered by the inferior mesenteric vessels as they pass down in the meso-sigmoid to reach the meso-rectum. In order to reach the artery in this situation, therefore, it will be necessary to make a vertical slit in the peritoneum just to the left of the middle line, and then to peel this structure outwards until the vessel is exposed. In doing this the large common and external iliac veins are also exposed. The ureter must be looked for and carefully avoided, as it would be disastrous to include it in the ligature, which should be passed from the vein, *i.e.* the inner, side.

On the right side, the operation is much easier, the artery being crossed by the termination of the ileum, which only requires to be pulled up, and the peritoneum can then be divided directly over the vessel. The operation is therefore much easier on the right side than on the left.

The coats of the vessel are approximated by a 'stay-knot' (see

p. 420), and when that has been tied and the ends cut short the incision in the peritoneum is closed by a fine catgut suture. The abdominal wall is closed in the usual way, as after laparotomy.

Difficulties and dangers. There are a few difficulties attending this form of the operation. The chief one is the difficulty in getting a good view of the artery; this is only of real importance in very fat subjects. When there is an immense amount of fat in the abdominal wall, the omentum, and the mesentery, &c., it becomes very difficult to get a clear field for operation. The difficulty is best obviated by the use of the Trendelenburg position; a clear view of the field of operation can be obtained after packing the intestines out of the way, and it should then be impossible to overlook the presence of the ureter and include it in the ligature.

On the right side it is a little difficult to clear the vessel so as to avoid the vein, but only patience is required.

LIGATURE OF THE INTERNAL ILIAC (HYPOGASTRIC) ARTERY

Indications. These will be very few. Almost the only condition for which the artery is likely to require ligature is an aneurysm in the gluteal region. The vessel may sometimes be tied as a preliminary to excision of the rectum by the abdomino-perineal method; it may be tied also as a preliminary to complete extirpation of the uterus.

If a gluteal aneurysm be present it is most difficult to ligature the superior gluteal artery, and the old operation of laying open the sac, turning out the clot, and securing the open mouth of the vessel is a very hazardous one.[1] Ligature of the internal iliac (hypogastric) artery, of which the superior gluteal is the terminal branch, is therefore a much simpler method. Similarly, when a gluteal abscess opens into the artery and forms a diffuse aneurysm in the buttock, it may be necessary to tie the internal iliac (hypogastric) trunk.

Ligature of the internal iliac (hypogastric) artery forms a recognized preliminary measure in the abdomino-perineal resection of the rectum recommended by Hartmann and Quénu, and I have performed it with ease and rapidity in two such cases. In panhysterectomy, on the other hand, it is not so generally necessary, as the uterine and vaginal vessels can be secured *seriatim* with comparative ease.

In certain cases of wounds of the buttock such as stabs or bayonet wounds, or injuries to the pelvis by means of firearms, there may be severe bleeding from a wound in the neighbourhood of the great sacro-

[1] See, however, the case reported by Abbé (see p. 385).

sciatic foramen, apparently from the gluteal artery. If slight enlargement of the wound does not allow the surgeon to secure the bleeding vessel, and if the loss of blood be severe, it will be wise to plug the wound firmly with gauze and adrenalin, and to open the abdomen with the view of securing the internal iliac (hypogastric) artery.

Anatomy. The artery is about one and a quarter inches long and extends from one side of the lumbo-sacral articulation to the upper margin of the great sacro-sciatic foramen, where it divides into its two terminal branches.

It is covered *in front* by the peritoneum and is crossed by the ureter. On the left side it is crossed by the rectum, which eventually lies on its inner side, and on the right side the coils of small intestine do the same. Both the external iliac (just before it becomes the common iliac) and the internal iliac (hypogastric) veins lie *behind* it, as do also the lumbo-sacral cord and the sacrum. It is separated from the inner edge of the psoas by the external iliac vein above. The obturator nerve also lies between it and the wall of the pelvis rather posterior to the vessel.

The operation is done by the trans-peritoneal method, in a manner similar to that described for the external iliac trunk. The extra-peritoneal route is so unnecessarily difficult and hazardous that it is not likely to be used and therefore will not be described.

After the abdomen has been opened and the intestines have been packed out of the way, the bifurcation of the common iliac is felt for and the internal iliac (hypogastric) artery is traced down into the pelvis. The peritoneum is incised over the artery, and the vessel cleared, and a ligature passed from whichever side may be most easy.

LIGATURE OF THE COMMON ILIAC ARTERY

Indications. (i) The chief affection for which ligature of the common iliac trunk will be required is an *aneurysm of the external iliac artery*. Owing, however, to the great risk of gangrene following ligature (*vide infra*) an attempt to preserve the circulation in the vessel by means of Matas's operation (see p. 382) will be probably preferred.

(ii) The vessel has been tied on several occasions for *wounds*—usually in association with gunshot injuries. These cases must obviously always be rare, as the condition is a very fatal one. Here again ligature will probably be abandoned in future in favour of arteriorrhaphy (see p. 379).

(iii) It has also been tried for *secondary hæmorrhage*, but this will hardly be necessary at the present time when secondary hæmorrhage has practically disappeared from surgery.

(iv) Either the common or the external trunk will be ligatured and divided in *removal of one half of the pelvis*.

Anatomy. The artery extends from the bifurcation of the aorta (three-quarters of an inch below and a little to the left of the umbilicus, opposite the middle of the fourth lumbar vertebra) to one side of the lumbo-sacral articulation, where it divides into its external iliac and internal iliac (hypogastric) branches.

The right common iliac artery is longer than the left and has behind it the commencement of the vena cava, both the common iliac veins, the psoas muscle, the lumbo-sacral cord, the obturator nerve, and the ilio-lumbar artery. *In front* it is covered by the peritoneum, the termination of the ileum, and sometimes by the head of the cæcum and the appendix. The ureter crosses it near its bifurcation, as do also the ovarian vessels in the female. To its *outer side* lie the vena cava, the upper end of the right common iliac vein, and the psoas. To its *inner side* is the right common iliac vein below and the left common iliac vein above.

The left common iliac artery is one and three-quarter inches long and has the same relations *in front* as the right, except that it is crossed by the sigmoid flexure and its meso-sigmoid, containing the superior hæmorrhoidal vessels, instead of the end of the ileum. *Behind,* it lies upon the fourth and fifth lumbar vertebræ, the obturator nerve, the ilio-lumbar artery, and the lumbo-sacral cord. To its *outer side* is the psoas; to its *inner side* are the left common iliac vein and the middle sacral artery.

Operation. The operation is done in all respects in the same manner as that for the trans-peritoneal ligature of the external iliac, except that in this instance it will be better to make the abdominal incision nearer to the middle line; it should therefore extend from an inch and a half above Poupart's ligament to just above the level of the umbilicus, and should be about an inch to its own side of the middle line. The anterior layer of the sheath of the rectus is opened, the inner margin of that muscle is defined and pulled outwards, and the posterior layer of the sheath and the peritoneum are divided in the usual manner. The Trendelenburg position is then adopted, and the intestines packed up out of the way.

The peritoneum is incised directly over the artery, and the ligature is passed as in the case of the external iliac. The *after-treatment* is also similar.

There is more than one method of applying a ligature to this vessel by the extra-peritoneal route which has been in vogue in the past, but which will be entirely abandoned in future in favour of the safer, more certain, and more rapid trans-peritoneal operation. The latter is so obviously superior, that the extra-peritoneal operation will not be described.

The ligature should be tied only tightly enough to approximate the coats of the vessel without dividing them, and it is well to use the 'stay-knot' with a double floss silk ligature as recommended by Ballance and Edmunds (see p. 420).

Results. Gillette (*Annals of Surgery*, vol. xlviii, 1908, p. 22)

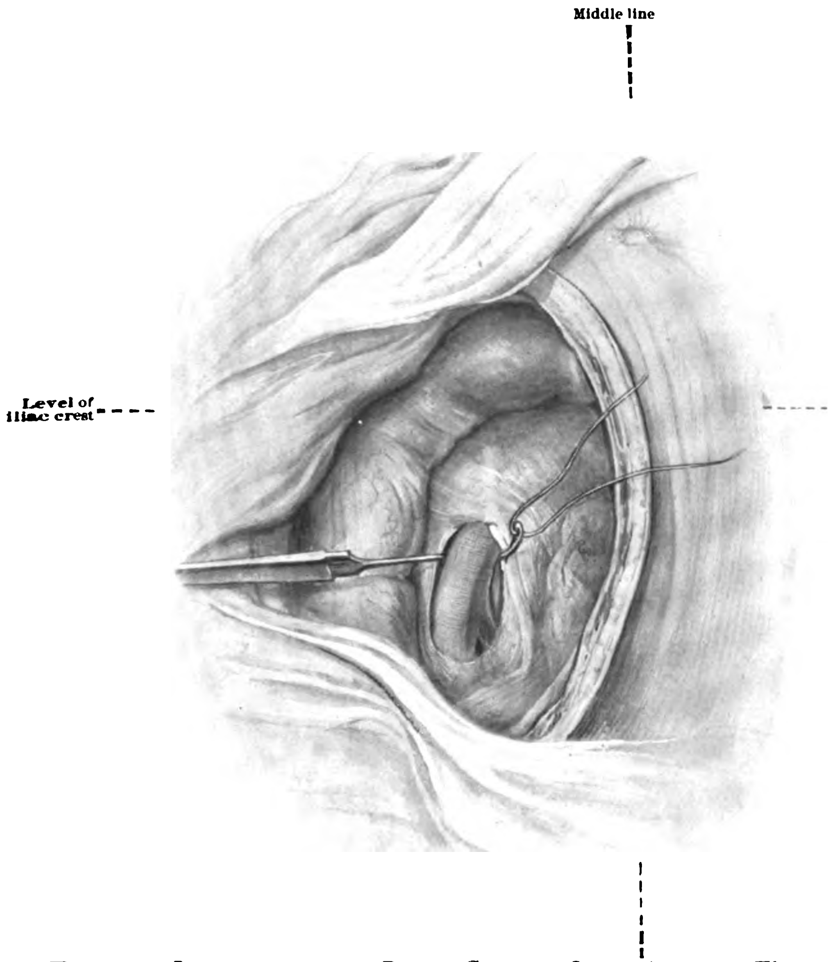


FIG. 190. LIGATURE OF THE RIGHT COMMON ILIAC ARTERY. The needle is passed around the vessel just above its bifurcation. The ureter is seen pulled towards the middle line and just denuded of its peritoneal covering in the upper part of the incision in the peritoneum.

reports a case of ligature of the common iliac for aneurysm of the sciatic artery. The ligature was practised through the peritoneum and tied close to the bifurcation of the aorta. Gangrene of the leg followed and amputation was done at the junction of the upper and middle thirds, but the flaps sloughed and finally a cure resulted after amputation six inches above the knee. He gives a summary of the cases reported, and mentions eighty cases with fifty-six deaths, or a death-rate of 70 per cent.; fifty-nine of these he classes as prior to the antiseptic era in 1880, and of these forty-six died, a death-rate of 77.97 per cent. Since 1880 twenty-one cases have been reported, presumably with proper antiseptic precautions, with a mortality of ten cases or 47.64 per cent. Gangrene of the leg has occurred in the last twenty-one cases seven times, *i.e.* 33⅓ per cent. Although the death-rate has been lowered by more improved methods the operation no doubt is still dangerous, chiefly owing to the risk of gangrene, and should be only employed in cases of absolute necessity.

LIGATURE OF THE SUPERIOR GLUTEAL ARTERY

Indications. This is practically only a dissecting-room operation; even then, however, it is scarcely a fair test of surgical ability, as the position in which the body lies causes the veins to become intensely congested and the soft parts to become water-logged, so that a clear view of the vessel is impossible.

At one time ligature of the vessel was done in the living subject for the cure of gluteal aneurysm, and for some cases in which the artery had ulcerated or ruptured into a gluteal abscess. Either of these conditions, however, should be treated by ligature of the internal iliac (hypogastric) artery by the trans-peritoneal method (see p. 460). No surgeon conversant with the difficulties in securing the vessel outside the pelvis would willingly face the extra-pelvic operation if he could do the comparatively easy trans-peritoneal ligature of the internal iliac (hypogastric) artery.

Anatomy. This vessel is the largest branch of the internal iliac (hypogastric) artery, and passes backwards out of the pelvis through the great sacro-sciatic foramen immediately above the pyriformis muscle, between it and the gluteus medius; the superior gluteal vein is superficial to it. The superior gluteal nerve emerges from the foramen below the artery. The artery divides into superficial and deep branches; the point of division is variable and sometimes is well inside the pelvis. The superficial branch passes directly upwards or backwards to supply the under-surface of the gluteus maximus, whilst the deeper branch accompanies the superior gluteal nerve between the gluteus medius and minimus.

The point of exit of the artery from the pelvis corresponds to the junction of the inner with the middle third of a line drawn from the posterior superior spine of the ilium to the top of the great trochanter, when the thigh is flexed and rotated slightly inwards. Another landmark is the junction of the posterior with the middle third of a line drawn from the anterior superior to the posterior superior spine of the ilium (Morris).

Operation. The patient lies as nearly in the prone position as the exigencies of the anæsthetic allow, and is drawn to the end of the table

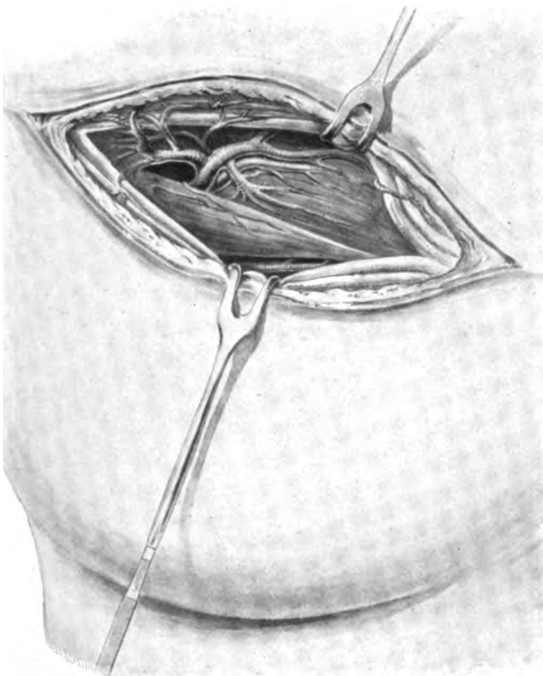


FIG. 191. THE SUPERIOR GLUTEAL ARTERY. The trunk of the vessel is seen emerging above the pyriformis and dividing into its terminal branches.

so that the affected limb hangs over its end; the thigh is rotated inwards. The surgeon stands on the affected side and makes an incision five inches long in the line from the posterior superior iliac spine to the great trochanter, the centre of the incision corresponding to the point of emergence of the vessel from the pelvis (*vide supra*). After the coarse skin and subcutaneous fat of the buttock have been incised, the fibres of the gluteus maximus are seen arranged in large bundles running practically in the line of the wound, and are pulled aside with broad retractors until the cellular interval between the under-surface of the gluteus maximus and the pyriformis and gluteus medius is reached. The surgeon must be careful to ascertain when he has reached this interval, as the appearances are rather deceptive, the gluteus maximus being intersected here and there with tracts of fatty cellular tissue which may lead to the erroneous conclusion that this interval has been reached some time before the thick muscle has been traversed entirely.

After the gluteus maximus has been divided completely, the leg is placed in the horizontal position so as to relax the muscles to the utmost, and the pyriformis and gluteus medius are identified; the interval between these two muscles is opened up, the upper margin of the pyriformis and the lower border of the great sacro-sciatic notch being carefully defined. Emerging from above the upper border of the pyriformis will be seen the superficial division of the artery, together with the superior gluteal nerve, and this should be traced downwards and inwards until the trunk of the vessel is reached (see Fig. 191). This is more difficult than the description would indicate, owing to the presence of numerous veins, and the fact that the branches of the gluteal often come off on a plane almost at right angles to that of the main trunk, so that there may be most embarrassing bleeding from a wound of these branches before the main trunk is reached. The ligature should be passed as far inside the pelvis as possible, always at least under cover of the edge of the great sacro-sciatic foramen. Aneurysm needles with various curves will probably be required, and a good artificial light will be necessary, especially in fat subjects.

LIGATURE OF THE SCIATIC (INFERIOR GLUTEAL) ARTERY

Ligature of this vessel also is a mere dissecting-room exercise. In the living subject it could only be required for some perforating wound, in which case obviously the wound would be enlarged and the bleeding spot identified and secured.

Anatomy. The artery, together with the internal pudic, escapes from the pelvis through the great sacro-sciatic foramen below the pyriformis muscle, between it and the gemelli. It rests upon the obturator internus and passes behind the internal pudic artery so as to reach its outer side, and is superficial or posterior both to the great and small sciatic nerves. Its point of exit from the pelvis corresponds to the junction of the lower with the middle third of a line drawn from the posterior superior iliac spine to the outer part of the tuber ischii. The artery not infrequently comes off from the anterior division of the internal iliac (hypogastric) artery in common with the internal pudic.

Operation. The positions of the patient and the surgeon are the same as in the preceding operation. An incision four inches long is made in the direction of the fibres of the gluteus maximus, and is so placed that its centre corresponds to the point of emergence of the vessel from the pelvis (*vide supra*). The steps of the operation are very similar to those of the previous one, the fibres of the gluteus maximus being separated as before, and the lower border of the pyriformis being identified after the whole thickness of the former muscle has been traversed. The

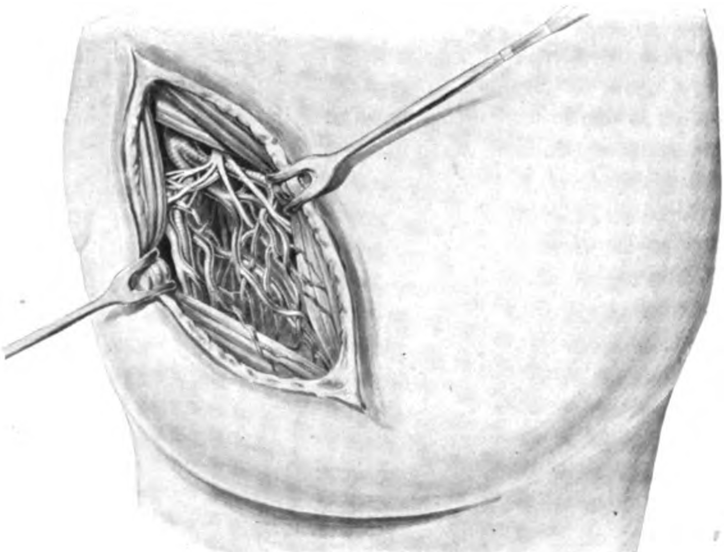


FIG. 192. THE SCIATIC AND INTERNAL PUDIC ARTERIES. Both vessels emerge beneath the lower border of the pyriformis as a single trunk. The internal pudic nerve is seen close to the left-hand retractor, which is pulling back the fibres of the gluteus maximus. The sciatic nerve breaking up into a number of branches is close to the retractor on the right-hand side.

artery is found and secured between the lower border of the pyriformis and the gemelli (see Fig. 192).

LIGATURE OF THE INTERNAL PUDIC ARTERY

Anatomy. This artery leaves the pelvis between the pyriformis and the coccygeus muscles along with the sciatic nerve. After leaving the pelvis the artery runs downwards, internal to the sciatic, over the spine of the ischium, and re-enters the pelvis through the small sacro-sciatic foramen.

The point at which this artery crosses the ischial spine corresponds to the junction of the inner with the middle third of a line drawn from the base of the coccyx to the top of the great trochanter when the femur is rotated inwards. This may help to locate the artery in cases of difficulty.

Operation. The positions of the patient and the surgeon and the incision are the same as in the preceding operation. After the lower border of the pyriformis has been defined, the ischial spine is identified and the artery is secured as it passes over it well internal to the position of the sciatic. The pudic nerve lies internal to the artery and should not be included in the ligature (see Fig. 192); the nerve to the obturator internus lies to its outer side.

The principal difficulty in the dead subject is to distinguish the artery from the sciatic, especially when the two arise from a common trunk.

CHAPTER IX

LIGATURE OF THE ABDOMINAL AORTA

ALTHOUGH no case of permanent ligature of the abdominal aorta has hitherto been successful, it cannot be said with justice that the operation is therefore removed from the sphere of practical surgery. The field for the operation must always remain very limited, and the number of those who will have the courage to apply a ligature in such an important and dangerous region will be probably even more limited still. It is possible, too, that the operation itself may undergo profound modification, and that ligature of the abdominal aorta in the true sense of the term may disappear from operative surgery within a short time, its place being taken either by the application of some form of temporary compression or by Matas's operation, a full account of which is given on p. 384.

Indications. There is practically only one indication for this formidable operation, namely, *aneurysm of the common iliac or of the aorta itself.* In *iliac aneurysm* ligature of the abdominal aorta will only be done when the aneurysm extends up along the artery as far as the bifurcation of the aorta, and Matas's operation is impracticable. With more modern methods and improved aseptic technique, aneurysm of the common iliac trunk should be amenable to less heroic measures than ligature of the aorta, as, owing to the size of the parts and their comparative accessibility in the Trendelenburg position after an abdominal section, it seems reasonable to suppose that Matas's operation should be of great value here. The large size of the vessel will render possible the 'reconstructive' suture in fusiform aneurysms that cannot be dealt with by the 'restorative' suture. Hence the great risk of ligation, viz. gangrene, may possibly be minimized.

In *aortic aneurysm* the operation must obviously take the form of proximal ligature, and therefore the point at which the ligature can be applied is determined by anatomical considerations. It will be impossible to tie the artery higher up than the root of the mesentery, which corresponds roughly to the origin of the inferior mesenteric branch. Above this the mesentery, the third portion of the duodenum, and the renal vessels effectually preclude any possibility of the application of a ligature. It is, therefore, only an aneurysm between the origin of the inferior mesenteric artery and the bifurcation of the aorta that could be successfully treated by proximal ligature, as in this region the vessel is comparatively accessible. It would seem, however, to one who has never had the opportunity of dealing with the condition, that it should be less dangerous as well as less difficult to control the circulation on each side of the aneurysm and then to incise the sac and treat it according to the plan suggested by Matas, making a special effort to preserve the circulation at the end of the operation by the use of the 'reconstructive' suture.[1]

The real difficulty, however, is not to decide which is the best method of treatment, for that will depend largely upon the conditions met with in any individual case and will probably be plainly apparent to the surgeon who has to deal with such a case; it is to say whether and when operative measures are called for in the treatment of abdominal aneurysm. Unfortunately no one possesses experience of a sufficiently large number of cases to entitle him to be dogmatic upon such an important subject. Aneurysm of the abdominal aorta between the origin of the inferior mesenteric and the bifurcation of the aorta is not of frequent occurrence. The majority of abdominal aneurysms occur at or above the origin of the cœliac axis (see Bryant, *Clinical Journal,* 1903). The prognosis is gloomy in the extreme; few patients live more than eighteen months after development of the aneurysm, and not many pass the first year. The disease is often marked by great pain, and the enforced rest practically disables the patient entirely. Surgical measures undoubtedly often prove directly fatal, and it can only very rarely be said that they are productive of any benefit at all.

The consideration of published cases leads to the conclusion that direct operative interference with the main artery, such as by ligature of the aorta or Matas's operation, will be called for in the rare cases in which

[1] Abbé (*Annals of Surgery,* 1908, vol. xlviii, p. 10) mentions his method of treatment of abdominal aneurysm published by him in the *New York Medical Journal,* 1894. This consists in clamping the aorta above and below, excising the affected area, and tying into the gap a glass tube of sufficient calibre. This was done in a cat, and four months afterwards the animal was shown with the tube healed firmly in her aorta. The blood flowed through it for days until the tube excited endarteritis. He makes a valuable suggestion that in cases of aneurysm of the aorta it may be possible to open the abdomen, clamp the aorta above and below, incise the sac, fasten in a glass tube through the aneurysmal cavity, and then to bring the aneurysmal wall together by Matas's method over the tube. It is undoubtedly a suggestion worth considering, the object being to secure gradual obliteration of the aorta and thus to give time for the collateral circulation to become established. It is, however, probable that Matas's 'reconstructive' suture (see p. 390) would serve the same purpose without the necessity of having to sew into the aorta a foreign body that was to remain *in situ* indefinitely.

the disease is diagnosed early and the tumour is small and circumscribed. Early resort to exploratory laparotomy for an obscure tumour of the abdomen may lead to this happy result, and under these circumstances better results may be hoped for from direct surgical interference in the future than has been the case in the past. On the other hand, the less directly operative procedures, such as Macewen's acupuncture treatment, or the introduction of wire into the sac, should be reserved for the cases in which the aneurysm has reached such a size that its boundaries are no longer clear and it has become so matted to surrounding parts that direct interference with the main artery would be difficult and even hazardous. If either of the methods referred to be employed, they should be practised after a laparotomy has been done to expose the wall of the sac so that the needles or the trocar and canula can be thrust through some safe spot where it is certain they will not transfix the intestinal wall or any important blood-vessel. Both Macewen's acupuncture and the method of introducing wire into the sac are dealt with in connexion with aortic aneurysm, for which they are more frequently used.

The other surgical affection that usually demands ligature of a vessel, namely *hæmorrhage,* does not call for the application of a ligature in the case of the aorta. Wounds of the aorta must necessarily be rare, and the vast majority from their very nature must prove fatal before any surgical measures can become available. There are, however, a few cases which may be satisfactorily treated. These will be small wounds and will chiefly occur in the course of operations; for example, the renal artery may be torn from the aorta at its origin. Should such a case occur, it could be dealt with satisfactorily by arteriorrhaphy. The circulation through the aorta is commanded on either side of the wound, which is then sutured in the appropriate manner (see p. 379). This treatment has the advantage that it is not only simpler but it preserves the lumen of the artery intact, and should therefore not be accompanied by any grave danger to life.

Operation. Two methods are always described, namely, the extra-peritoneal and the trans-peritoneal methods. In the present state of operative surgery it would seem to be a mere waste of time to describe the extra-peritoneal method, which, however excellent a purpose it may have served in the past, is barbarous and unscientific when compared with the trans-peritoneal operation.

The patient should undergo a preliminary treatment for a week or more destined to evacuate the bowels thoroughly and to keep them empty, as distended intestines are a most fruitful source of inconvenience during the operation; the rest of the preparation is the same as for an ordinary laparotomy. The incision is made one inch to the left of the middle line downwards for nearly five or six inches from a point three inches above the umbilicus. The anterior sheath of the rectus is divided in the line of the incision and the inner border of that muscle is defined and pulled outwards and then the posterior sheath of the rectus and the peritoneum are opened. The patient is now put in the Trendelenburg position and the intestines are packed up out of the way with suitable sterilized cloths. Particular care must be taken

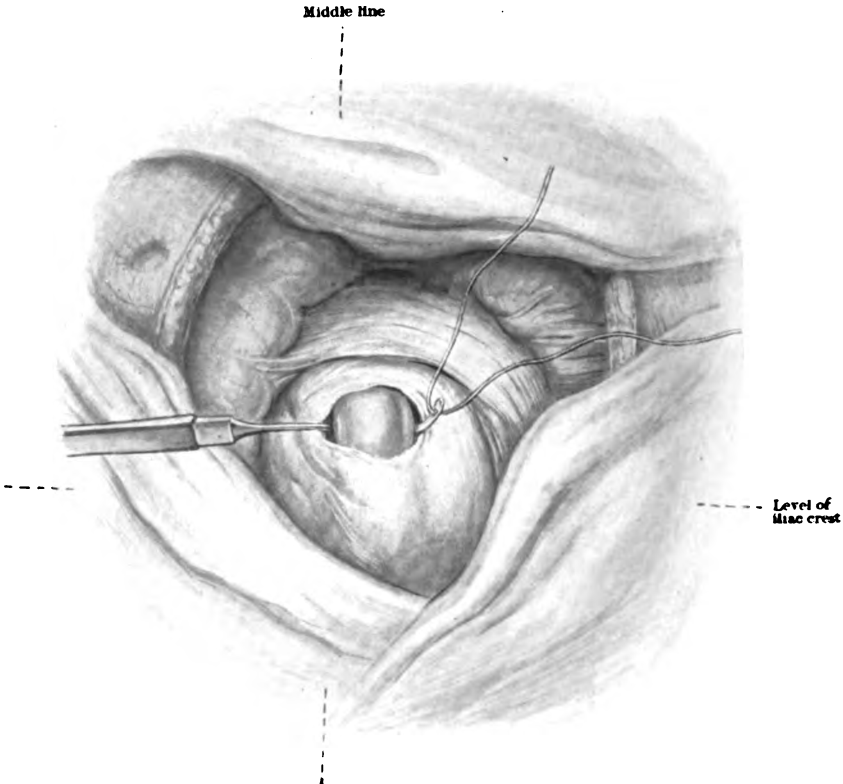


FIG. 193. LIGATURE OF THE ABDOMINAL AORTA. The vessel is secured just above its bifurcation and below the origin of the inferior mesenteric artery.

to see that the small intestine is thrown well up into the upper part of the abdomen; the sigmoid flexure can be allowed to fall into the pelvis out of the way, if necessary. The artery and the aneurysm will be thus rendered visible. The operator defines the vessel above the sac, and, whatever he intends to do subsequently, proceeds to clear the vessel for the application of a ligature. The peritoneum and the sheath of the vessel should be opened separately with great care as far over to the left side as possible, and the most difficult step of the operation, namely the clearing of the artery, is then undertaken. It is most important to avoid including the aortic plexus of the sympathetic in the ligature. The clearing of the vessel must be done with the greatest care and several directors or aneurysm needles with suitable curves must be at hand.

When the vessel has been cleared satisfactorily the surgeon applies either a permanent or a temporary ligature (see Fig. 193) according as he is going to make use of ligation in continuity or Matas's operation. In the former case the ligature should certainly consist of two, or preferably of four, strands of soft material, such as floss silk or even kangaroo tendon, each ligature being drawn tight in regular order so that the first will break the force of the circulation and allow the second and subsequent ones, which are applied on the distal side of the first, to approximate the wall of the vessel sufficiently to control the circulation through it. On no account should sufficient force be exerted to rupture the inner coats, and it will be well to make use of the 'stay-knot' advocated by Ballance and Edmunds (see p. 419). If four ligatures are used it is a good plan to group the ligatures into two sets, tying the second loop of each knot with two ligatures on either side (see Fig. 168). The incision into the peritoneum is sutured, the abdominal cavity is closed in the usual way, and the patient kept in the Trendelenburg position until he is put back in bed. Every precaution must be taken against shock before, during, and after the operation. After the operation the extremities must be wrapped up in cotton wool and kept elevated on pillows and by raising the foot of the bed on blocks.

LIGATURE OF THE ARTERIES OF THE UPPER EXTREMITY

CHAPTER X

LIGATURE OF THE ARTERIES OF THE HAND AND FOREARM

LIGATURE OF THE RADIAL ARTERY

Indications. (i) *Wounds.* These are frequently met with in any part of the vessel. The best plan is to cut down directly upon the bleeding spot in the line of the vessel, making use of the original wound, and to secure the cut ends with ligatures.

(ii) *Aneurysms.* These may be either of the traumatic—chiefly met with about the wrist—or the arterio-venous variety; the latter used to be frequently met with about the bend of the elbow in the days when venesection was in vogue, and generally affected the brachial trunk. Aneurysms of the radial artery are not likely to be too large to prevent them from being excised completely after the circulation in the limb has been commanded by an Esmarch bandage.

(iii) *Wounds of the palmar arch.* In order to check bleeding from this cause, the radial and the ulnar arteries have been ligatured simultaneously just above the wrist when the wounded vessel could not be found after enlarging the incision in the palm. It is hardly likely that this treatment would be followed at the present day, however. The circulation in the limb should be controlled, the wound enlarged, and the bleeding points secured. In neglected septic cases, however, the artery may have to be tied if secondary hæmorrhage sets in. Most surgeons, however, prefer to tie the brachial artery at the bend of the elbow if they cannot secure the bleeding points.

Surgical anatomy. The radial artery is the smaller of the two terminal divisions of the brachial, and is a direct continuation of it. It extends from the middle of the front of the elbow to the back of the first interosseous space, where it dips down to join the deep branch of the ulnar artery. Its anatomical line is drawn from the centre of the front of the bend of the elbow to the line of the pulse, namely, just external to the tendon of the flexor carpi radialis (see Fig. 194).

In the forearm the artery lies in succession upon the tendon of the biceps, the supinator (brevis), the pronator teres, the radial portion of the flexor digitorum sublimis, the flexor pollicis longus, the pronator quadratus, and the anterior ligament of the wrist-joint. It is overlapped in the upper part of its course by the anterior margin of the supinator longus (brachio-radialis), but lower down it becomes subcutaneous. On its outer side is the supinator longus (brachio-radialis) or its tendon throughout, and the radial nerve in the middle third; elsewhere in its course the nerve is not in relation with the artery. On the inner side

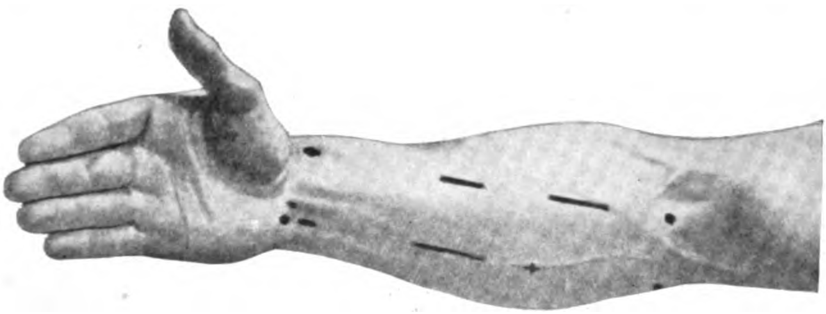


FIG. 194. INCISIONS FOR THE RADIAL AND ULNAR ARTERIES ON THE FRONT OF THE FOREARM. The three upper incisions are those for the radial artery, and the upper pair of dots are placed respectively on the centre of the ante-cubital fossa and the pulse at the wrist. The lower two incisions are for ligature of the ulnar artery, the lower pair of dots being placed, one upon the tip of the internal condyle and the other upon the pisiform bone. The + is at the junction of the upper with the middle third of this line and corresponds to the point at which the ulnar artery joins it. The upper third of the ulnar artery is denoted by a line between the upper right-hand dot and the + with a slight convexity towards the inner side of the forearm.

lies the pronator teres, with the flexor carpi radialis below. There are two venæ comites, one on each side of the artery.

In its course from the front of the forearm to the back of the wrist, the radial artery lies upon the external lateral (radial) ligament of the wrist-joint, the scaphoid (navicular), the trapezium (great multangular), and the base of the first metacarpal. Superficial to it are the tendons of the extensor ossis metacarpi pollicis (abductor pollicis longus), the extensor pollicis brevis, and the extensor pollicis longus. Above this is the fascia, in which are branches of the radial nerve and the commencement of the radial vein. The line of this part of the vessel is from the tip of the styloid process to the upper end of the first metacarpal space (see Fig. 198).

The artery may be tied in its upper, middle, or lower thirds. It is also sometimes tied at the back of the wrist in what is known as the 'anatomical snuff-box'; this, however, is only a dissecting-room exercise.

LIGATURE IN THE UPPER THIRD OF THE FOREARM

The arm is fully supinated and supported at right angles to the trunk upon a suitable table or rest; the surgeon stands on the outer side of

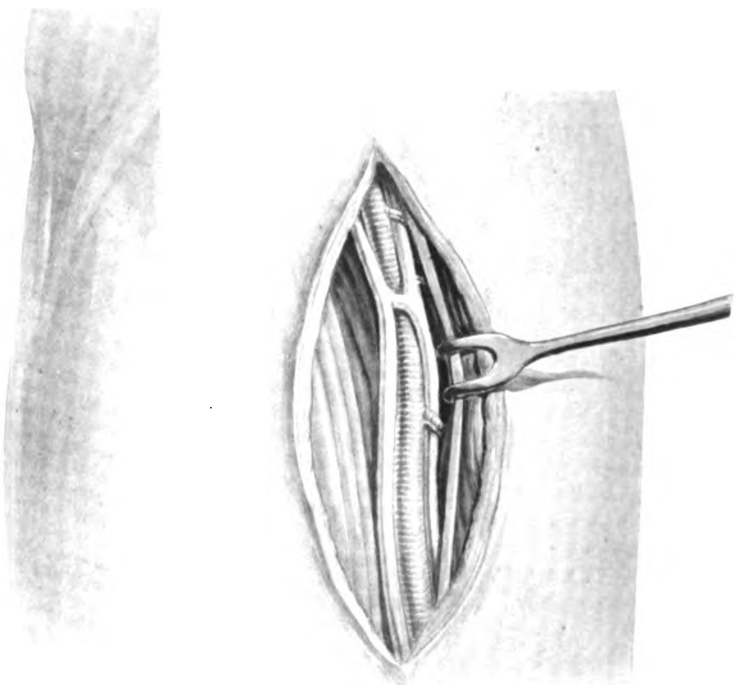


FIG. 195. THE RADIAL ARTERY IN THE UPPER THIRD OF THE FOREARM. The hook pulls back the supinator longus (brachio-radialis) and the superficial radial vein. The muscle on the inner side of the artery is the pronator (radii) teres. The radial nerve is not seen.

the limb. An incision two and a half inches long is made along the line of the artery (*vide supra*) in the upper third of the forearm. A few branches of the radial vein are divided, and the deep fascia is opened up throughout the length of the wound. The interval between the supinator longus (brachio-radialis) externally and the pronator teres internally is then sought for. The situation of this interval is very variable, and depends upon the muscular development of the limb; it is best found by noting the direction of the muscular fibres, those from the supinator longus (brachio-radialis) passing directly down the forearm, whilst those of the pronator pass from the internal condyle obliquely downwards and outwards to the radial side. When the interval has been found, the inner margin of the supinator longus (brachio-radialis) is defined,

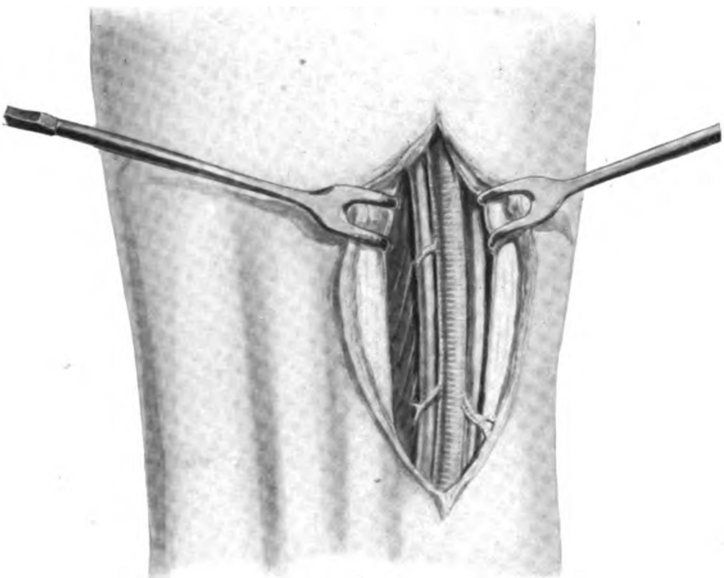


FIG. 196. THE RADIAL ARTERY IN THE MIDDLE THIRD OF THE FOREARM. The right-hand retractor is pulling back the supinator longus (brachio-radialis), immediately internal to which is seen the radial nerve on the outer side of the artery, approaching it somewhat obliquely from above. The artery is seen with its vena comes on its inner side lying upon the insertion of the pronator (radii) teres.

first by a few touches of the point of the knife and then by its handle, and the muscle is pulled outwards with a retractor and the artery is seen lying beneath it (Fig. 195). In a muscular limb the wrist and elbow joints will need to be flexed in order to facilitate retraction of the muscle and access to the artery. The venæ comites are separated from the artery if possible, but, if necessary, may be taken up in the ligature; the latter is usually passed from without inwards.

LIGATURE IN THE MIDDLE THIRD OF THE FOREARM

The positions of the limb and the operator are the same as before. The incision should be two inches long, in the line of the artery (see p. 474), and its centre should correspond to the middle of the forearm. After the deep fascia has been opened up, the inner margin of the supinator longus (brachio-radialis) is defined as before, and drawn well outwards with a retractor. The artery lies upon the insertion of the pronator teres, and is bound down to it by a special fascia. The

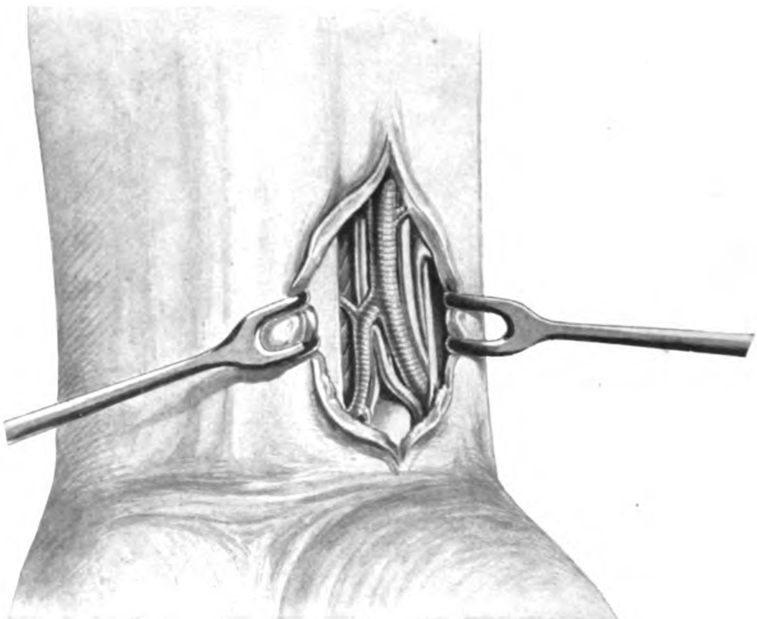


FIG. 197. THE RADIAL ARTERY AT THE WRIST. The artery, with the superficialis volæ arising from it, is seen between its venæ comites.

(superficial) radial nerve lies close to its outer side (see Fig. 196), and the needle should therefore be passed from the outer side.

LIGATURE IN THE LOWER THIRD OF THE FOREARM

Here the vessel is only covered by the skin and superficial fascia, while some of the branches of the superficial radial vein and a few cutaneous nerves lie over it.

The position of the limb is the same as before (see p. 476), and the surgeon makes an incision half an inch long in the line of the artery (see p. 474), just external to the tendon of the flexor carpi radialis. Care must be taken in making this incision to go very lightly through the skin, as the fascia is thin, and the radial artery may be wounded at the first cut if too much force be used. When the deep fascia is reached it is incised, and the artery at once comes into view with its venæ comites (see Fig. 197); these are separated and the vessel is secured. The (superficial) radial nerve does not come into relation with the artery,

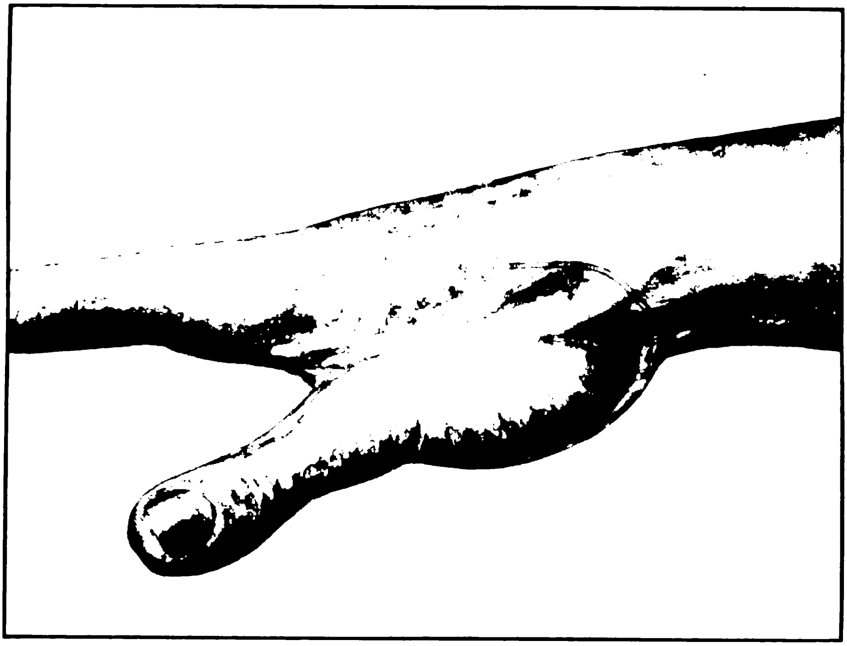


FIG. 198. THE LINE OF THE RADIAL ARTERY IN THE 'ANATOMICAL SNUFF-BOX'. The tendons of the extensors of the wrist are well shown. A dot is placed upon the styloid process of the radius.

having turned beneath the supinator longus (brachio-radialis) to the back of the wrist.

LIGATURE IN THE 'ANATOMICAL SNUFF-BOX'

This is a dissecting-room operation. The hand rests upon its ulnar border, and the thumb is held by an assistant in a position of full abduction. If the outline of the tendons can be made out, an incision three-quarters of an inch in length is made parallel to and to the radial side of the extensor secundi internodii pollicis (extensor pollicis brevis) tendon, avoiding, if possible, the large branch of the superficial radial vein which crosses the snuff-box somewhat obliquely. The incision is deepened until the deep fascia is reached, and this is divided throughout the full length of the wound without opening the tendon sheaths; they should be pulled apart with blunt hooks while the vessel is sought for. The artery lies in some fatty tissue close upon the wrist-joint and surrounded by its venæ comites; it should be secured just before it reaches the upper end of the first metacarpal space.

If the outlines of the tendons cannot be made out, as may be the case in the dead subject, a simple plan is to make an incision along the line of the artery from the styloid process of the radius to the upper end of the first metacarpal space (see Fig. 198). This incision is parallel to the vessel throughout, whereas the previous incision crosses it at an angle. The steps of the operation are the same as above.

LIGATURE OF THE ULNAR ARTERY

Indications. Similar to those for the radial artery (see p. 474).

Surgical anatomy. The ulnar artery is the larger of the two branches into which the brachial divides, and it extends from the mid-point of the ante-cubital fossa on the front of the elbow, opposite the neck of the radius, to the palm of the hand, where it forms the superficial palmar arch.

The course of the lower two-thirds of the artery is indicated by a line drawn from the back of the internal condyle of the humerus to the radial side of the pisiform bone. The upper third of the vessel is indicated by a curved line with its convexity to the inner or ulnar side, extending from the mid-point of the ante-cubital fossa to the junction of the middle with the upper third of the first line (see Fig. 194).

Posteriorly the artery rests from above downwards upon the lower part of the brachialis (anticus), the flexor digitorum profundus, and the deep part of the anterior annular (transverse carpal) ligament. *Anteriorly* it is crossed by the pronator teres, the median nerve—which is separated from the artery by the deep head of the pronator—the flexor digitorum sublimis, the flexor carpi radialis, and the palmaris longus. In the middle third of the forearm it is overlapped by the anterior border of the flexor carpi ulnaris, and lower down still it becomes subcutaneous. *Laterally* it is accompanied by venæ comites; and on the ulnar or inner side lie the ulnar nerve and the flexor carpi ulnaris in the lower two-thirds. On the radial side the flexor digitorum sublimis is found in its lower two-thirds.

The artery is usually tied either just above the wrist or in the middle of the forearm. It can be reached in its upper third, but here it is very deeply placed, and it would only be exposed for a wound of the vessel, in which case the existing wound would be enlarged.

LIGATURE IN THE LOWER THIRD OF THE FOREARM

The limb is fully supinated and rests on a suitable support. An incision half an inch long is made along the line of the artery (*vide supra*) through the skin and deep fascia; this should extend down to within a quarter of an inch of the pisiform bone, and should lie just to the radial border of the flexor carpi ulnaris tendon. When the deep fascia has

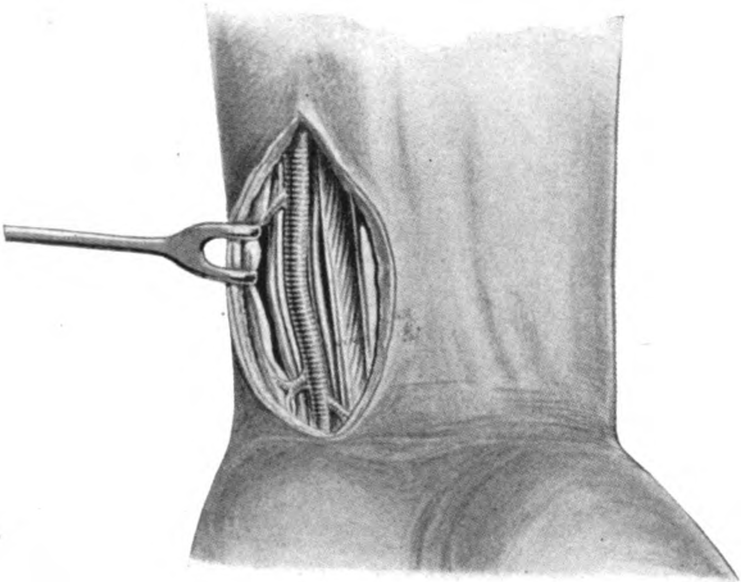


FIG. 199. THE ULNAR ARTERY AT THE WRIST. The tendon of the flexor carpi ulnaris is hooked back, and the artery is seen lying on the flexor sublimis. The nerve is to its inner side over the internal vena comes.

been opened, the artery comes into view, with the nerve on its inner or ulnar side (see Fig. 199). The needle should be passed from the nerve. viz. from the inner side.

LIGATURE IN THE MIDDLE OF THE FOREARM

The position of the limb is the same as before, and an incision is made three to four inches in length with its centre opposite the middle of the forearm along the line of the artery (see p. 480). The deep fascia is opened throughout the whole length of the wound, and the radial border of the flexor carpi ulnaris is sought for. There is often a well-marked intermuscular septum between this muscle and the flexor digitorum sublimis which may contain a considerable quantity of fat. Into this septum the handle of the knife is sunk, and the flexor carpi ulnaris is pulled gently to the inner side. As this is done, the elbow and the wrist should be flexed in order to enable the muscle to be drawn well back with retractors. The artery, with the nerve on its inner side, is then disclosed lying beneath the flexor carpi ulnaris (see Fig. 200). It

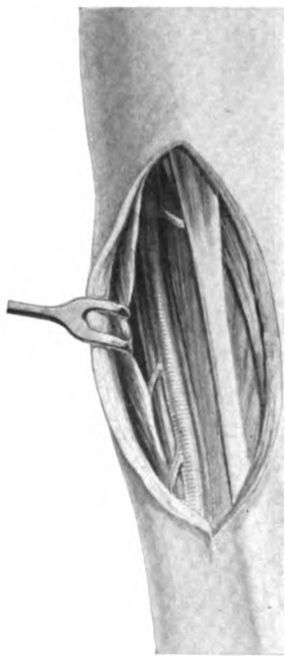


FIG. 200. THE ULNAR ARTERY IN THE MIDDLE OF THE FOREARM. The artery lies deeply under the flexor carpi ulnaris with the nerve to its inner side.

is cleared, and the needle is passed from the inner side. The nerve is generally seen first and forms the guide to the artery.

Difficulties and dangers. This operation is often difficult, especially in the dead subject, where the pulsation of the artery cannot be felt. The chief difficulty lies in identifying the outer border of the flexor carpi ulnaris, and the intermuscular septum between it and the flexor digitorum sublimis. In a well-developed muscular subject this septum may be some distance outside the line of the artery, and this fact must be remembered. The most useful guide to the position of the septum will be found in the presence of small intermuscular vessels which are always found in it, and which, when followed up, will lead to its identification and to the artery. The septum usually mistaken for the one in question is that between the flexor carpi ulnaris and the extensor muscles. This mistake is only likely to happen when the line of the artery has been taken incorrectly, and the incision made too far to the ulnar side of the forearm. If, on the other hand, the incision be made too far to the radial side of the artery, the septum between the palmaris longus and the flexor sublimis may be mistaken for the one in question.

LIGATURE IN THE UPPER THIRD

This, as already said, is not a recognized operation, as the first part of the artery is too deeply placed to be easily accessible; as a rule it is only undertaken for a wound of the vessel, when it suffices to enlarge the wound and to find the seat of the injury. The operation is, however, sometimes set at examinations, and it will then be found easy to secure the vessel through a vertical incision about three inches long, slightly to the ulnar side of the middle line, and having its centre just above the upper or outer border of the pronator teres, which may be indicated roughly by a line drawn from the internal condyle to the middle of the radius. When the deep fascia has been divided, the upper border of the pronator is defined and pulled downwards with a retractor; it is easy to identify this muscle from the direction of its fibres, which run downwards and to the radial side. By a little dissection the bifurcation of the brachial artery is exposed, and the ulnar artery is then traced downwards to the point at which it is desired to apply the ligature. If there be any doubt, the median nerve, which crosses the ulnar artery, will form a useful guide.

CHAPTER XI

LIGATURE OF THE ARTERIES OF THE UPPER ARM AND AXILLA

LIGATURE OF THE BRACHIAL ARTERY

Indications. (i) *Wounds of the artery.* In these cases the wound will be enlarged and the divided ends secured by ligature.

(ii) *Wounds of the palmar arch.* If the bleeding be persistent and cannot be stopped by the application of firm pressure, ligature of the brachial artery may be necessary. This operation is more satisfactory than ligature of the radial and ulnar arteries separately, owing to the free anastomosis about the wrist; the artery should be tied at the bend of the elbow. It will probably only be in cases of secondary hæmorrhage from a septic wound that this will be required. In a recent wound the parts would be made aseptic, the circulation controlled by an Esmarch bandage, the wound enlarged and the bleeding points identified and secured.

(iii) *Aneurysm* either traumatic or spontaneous will call for ligature of the vessel, but this affection is not common nowadays. Formerly an arterio-venous aneurysm at the bend of the elbow was a common sequela of venesection.

Surgical anatomy. The brachial is the direct continuation of the axillary artery, and extends from the lower border of the teres major to the middle of the ante-cubital fossa.

Anteriorly it is overlapped by the inner margin of the biceps, and is crossed about its centre by the median nerve, which passes from its outer to its inner side. The median (basilic) vein lies immediately over the artery at the bend of the elbow, being separated from it only by the deep fascia and the bicipital fascia (lacertus fibrosus of the biceps).

Posteriorly it lies upon the front of the long head of the triceps, upon the internal head of the same muscle, and, lower down, upon the insertion of the coraco-brachialis and the origin of the brachialis (anticus) muscles.

The musculo-spiral (radial) nerve and the (superior) profunda artery separate it above from the outer head of the triceps. *To its outer side* lie the coraco-brachialis and the median nerve above and the triceps below; *to its inner side* lie the median nerve below, and the basilic vein, the internal (medial antebrachial) cutaneous, the lesser internal (medial brachial) cutaneous, and the ulnar nerves above. It has two venæ comites.

The course of the artery is denoted by a line drawn from the junction of the upper with the middle third of a perpendicular let fall from the anterior to the posterior fold of the axilla, down to the centre of the ante-cubital fossa. In practice the line made use of is that corresponding

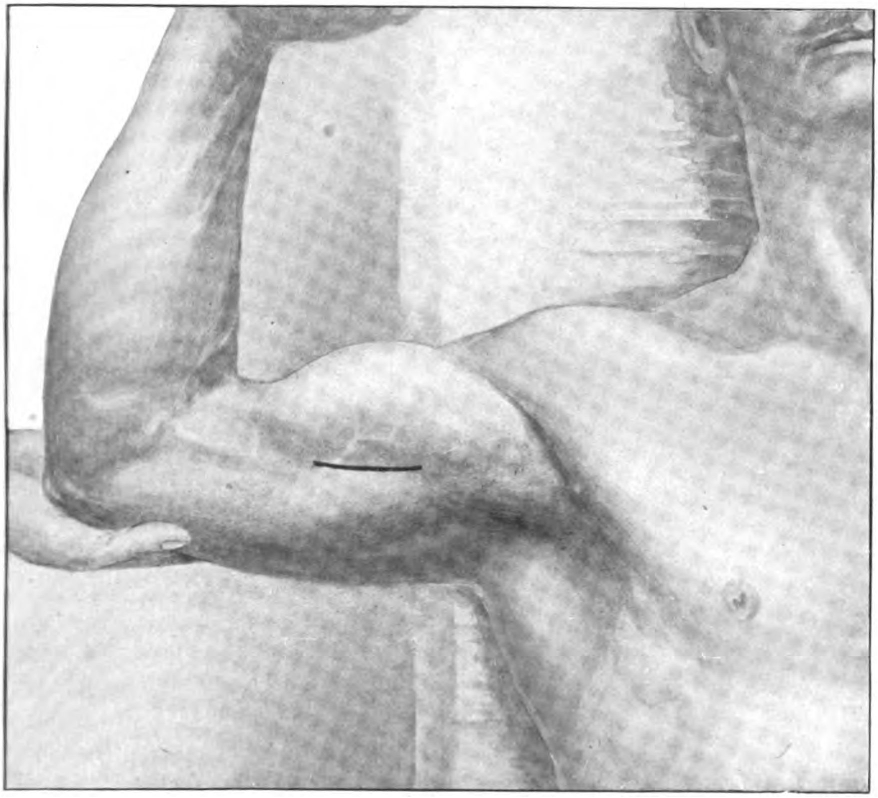


FIG. 201. INCISION FOR LIGATURE OF THE BRACHIAL ARTERY IN THE MIDDLE OF THE ARM. The elbow is supported by an assistant, so that the triceps shall hang free.

to the inner edge of the biceps muscle, which can always be seen even in fat subjects.

The artery is tied either in the centre of the arm or in front of the bend of the elbow.

LIGATURE IN THE MIDDLE OF THE ARM

An assistant holds the arm horizontal and at right angles to the trunk (see Fig. 201). The limb may be supported in that position by resting the tip of the olecranon on a sand-bag, but under no circumstances should the arm rest with the triceps flat upon a board or upon the table. The surgeon, who will find it most convenient to sit upon a stool between the trunk and the limb, makes an incision two and a half inches long in the line of the artery and over the inner border of the biceps muscle; the basilic vein must be avoided should it lie beneath the incision. The deep fascia is incised throughout the length of the wound and the inner

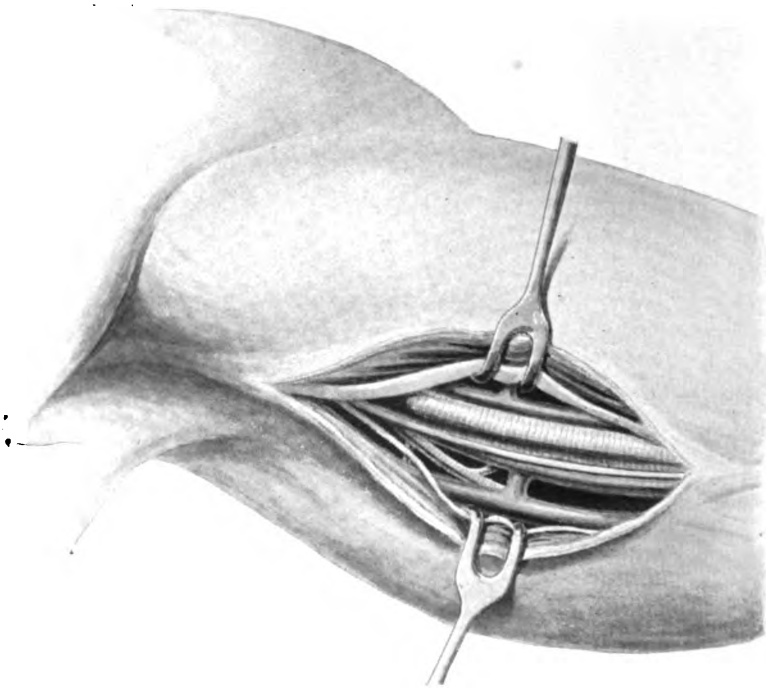


FIG. 202. THE BRACHIAL ARTERY IN THE MIDDLE OF THE ARM. The median nerve is hooked up, and the triceps, with the lesser internal (medial brachial) cutaneous nerve, is hooked downwards. Just below the artery is the internal (medial antebrachial) cutaneous nerve.

border of the biceps is defined and drawn outwards and upwards. The finger inserted into the wound will feel the pulsation of the artery in the living subject, or the hard rounded cord formed by the median nerve in the cadaver. The latter structure is defined by a few touches of the knife and raised in a hook. If the artery be exposed exactly at the centre of the limb, the median nerve will be crossing in front of it, while above this it will be to its outer and below it to its inner side. As long as the incision is not below the centre of the limb, it is best to draw the median nerve outwards or upwards in a retractor; if the artery has been exposed below the centre of the arm the nerve should be pulled inwards. The artery is thereby exposed with its venæ comites, of which the lower or inner one is generally larger than its fellow (see Fig. 202). The artery is separated from the veins, its sheath is opened and the needle is passed from without inwards.

Difficulties and dangers. Although this artery can generally

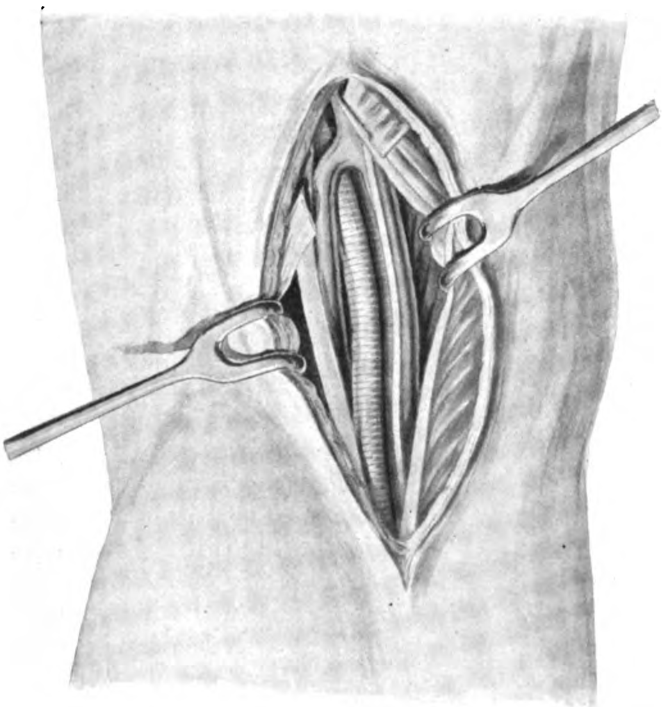


FIG. 203. THE BRACHIAL ARTERY AT THE BEND OF THE ELBOW. The bicipital fascia has been divided above, exposing the artery and its venæ comites. On its inner (left-hand) side is the large median nerve.

be felt through the skin before the operation, even in the dead subject, it is remarkable how many mistakes are made when it is cut down upon, especially in the dead subject. Even in the living subject the operation may be difficult owing to feeble pulsation of the vessel. The most important point in operating is to keep to the proper line of the vessel, namely, the inner border of the biceps muscle. For this reason it is most important that the triceps should hang free; if it be displaced upwards, the incision will be too far downwards or inwards, and the basilic vein will probably be wounded and the ulnar nerve exposed and mistaken for the median. The chief aid to successful operation is finding the median nerve; when this has been done, the brachial artery can be identified and tied without disturbing the surrounding structures, but if these latter be dissected out separately the operator soon becomes confused and fails to identify them. Another source of confusion is that the brachial artery is frequently abnormal in its distribution.

LIGATURE AT THE BEND OF THE ELBOW

The limb is abducted and the forearm is supinated and steadied upon a suitable sand-bag or rest. The elbow should not be too fully extended; if it is, the artery may be wounded in making the skin incision, as it lies close to the surface and becomes unduly prominent when the elbow is over-extended. The surgeon stands on the outer side of the limb, and feels for the inner border of the biceps tendon. He also should render the median basilic vein prominent by compressing it above so that it may not be cut in making the skin incision, which should be about one and a half inches long and parallel to and over the inner border of the biceps tendon; its upper extremity should be on the level of the tip of the internal condyle. When properly planned this incision will be parallel to the median basilic vein and to its outer side. The thin fascia in the front of the elbow is divided throughout the length of the wound, and then the bicipital fascia (lacertus fibrosus of the biceps), which may be recognized by its curved fibres running downwards and inwards, is divided fully. This exposes the brachial artery and its venæ comites (see Fig. 203); as a rule no other structure comes into view. The median nerve lies nearly half an inch to its inner side, and is not actually in relation with the vessel. The artery should be separated from its venæ comites and the needle passed from the inner side.

LIGATURE OF THE AXILLARY ARTERY

Indications. (i) *Wounds of the artery.* These are not uncommon; punctured wounds are often met with both in civil and military practice.

(ii) *Brachial aneurysm* situated too near to the commencement of the brachial artery to allow that vessel to be tied.

(iii) *Subclavian aneurysm.* Ligature of the axillary is occasionally done as the distal operation for an aneurysm of the subclavian artery in which it is impossible to apply a ligature on the proximal side.

(iv) Occasionally the axillary artery has to be ligatured *during removal of malignant glands* from the axilla, either because the vessel is accidentally wounded or because the sheath of the artery is invaded by the growth.

(v) Very rarely ligature may be required for *rupture of the axillary artery* following attempts to reduce a long-standing dislocation of the shoulder.

(vi) Ligature of the axillary forms part of *the old operation for axillary aneurysm*, by incision and evacuation of the contents of the sac.

Surgical anatomy. The axillary artery extends from the lower border of the first rib to the lower border of the teres major. It is usually divided into three parts; as a rule a ligature is only applied to the first and third parts.

The line of the artery is from the middle of the clavicle to the junction of the upper with the middle third of a perpendicular let fall from the anterior to the posterior fold of the axilla when the arm is abducted to a right angle with the trunk. It should be remembered that the line of the vessel varies with the position of the arm and, in particular, the relation of the vein to the artery is modified thereby. Thus, when the arm is drawn down to the side, the vein lies to the inner side of and somewhat below the artery, but when the arm is at right angles to the trunk or when it is raised above the head, the artery is completely hidden by the vein, which then lies in front of it. The vein varies greatly in size with respiration.

It is worth noting that the upper border of the pectoralis minor is on a level with the outer border of the first rib and that therefore, strictly speaking, no part of the artery is above this muscle. The distinction, however, is convenient as indicating that the artery is accessible both above and below this structure.

Relations of the first part of the artery. *Behind*, the vessel lies upon the first digitation of the serratus magnus (anterior) muscle, the first intercostal space with its contents, and the posterior or long thoracic nerve.

In the front are the costo-coracoid membrane (coraco-clavicular fascia), which separates the artery from the cephalic vein, and the external anterior thoracic nerve and the acromio-thoracic (thoraco-acromial) vessels. Superficial to these are the clavicular fibres of the pectoralis major, the deep fascia, platysma, and the descending clavicular branches of the cervical plexus.

Above, and to the outer side, are the cords of the brachial plexus.

Below, and to the inner side, are the axillary vein and the internal anterior thoracic nerve.

Relations of the third part of the artery. *Behind*, the vessel lies upon the lower border of the subscapularis, the latissimus dorsi and the teres major muscles. The circumflex (axillary) and the musculo-spiral (radial) nerves pass behind this part of the vessel.

In front, the artery is crossed by the inner head of the median nerve, and above it is covered by the pectoralis major muscle, the lower portion being covered only by the skin and fascia of the axilla.

To the outer side are the median and the musculo-cutaneous nerves, and the coraco-brachialis muscle.

To the inner side lies the axillary vein, but between this structure and the artery there intervene the ulnar nerve in the angle behind, and the internal cutaneous (medial antebrachial) nerve in the angle in front. The lesser internal (brachial) cutaneous nerve lies internal to the vein. The brachial venæ comites unite to form the axillary vein at the lower border of the subscapularis muscle.

LIGATURE OF THE FIRST PART

This operation is of the greatest rarity in the living subject, and the depth at which the artery is situated and the proximity of a number of important branches render it very difficult and dangerous. The surgeon would therefore always ligature the third part of the subclavian in preference to the first part of the axillary if he has the choice. It is, however, a favourite examination operation upon the dead subject.

The operation may be done in three ways: (i) Through a curved incision below the clavicle. (ii) Through one directly over the line of the artery. (iii) Through the interval between the deltoid and the clavicular fibres of the pectoralis major. Of these methods the first is probably the best, as it gives ample room and only involves division of some of the fibres of the pectoralis major. Operations upon the breast amply demonstrate that so small a damage as this to the pectoralis major is of no material consequence. This method is the only one that will be described; the others are distinctly inferior to it, inasmuch as they do not furnish such easy access to the vessel.

Operation. The thorax is slightly raised on a pillow and the arm is abducted almost to a right angle with the trunk in order to put the fibres of the pectoralis major on the stretch. The surgeon stands between the body and the limb, and makes an incision extending from the junction of the middle with the inner third of the clavicle to a point just outside the coracoid process. This incision should have a gentle convexity downwards. It is usually recommended that the incision should extend from the sterno-clavicular articulation, but this is unnecessary except in very fat people or cases in which there is much œdema, as most of the operation is performed at the outer end of the wound, and such a long incision is unnecessary. The skin, superficial fascia and platysma, with the supra-clavicular branches of the cervical plexus, are divided. The next step is to cut through the clavicular fibres of the pectoralis major exposed in the wound a finger's breadth below the clavicle; this will leave enough muscular fibre to allow of the cut surfaces being brought together at the end of the operation. Damage to the cephalic vein at the outer end of the wound must be avoided, and the acromio-

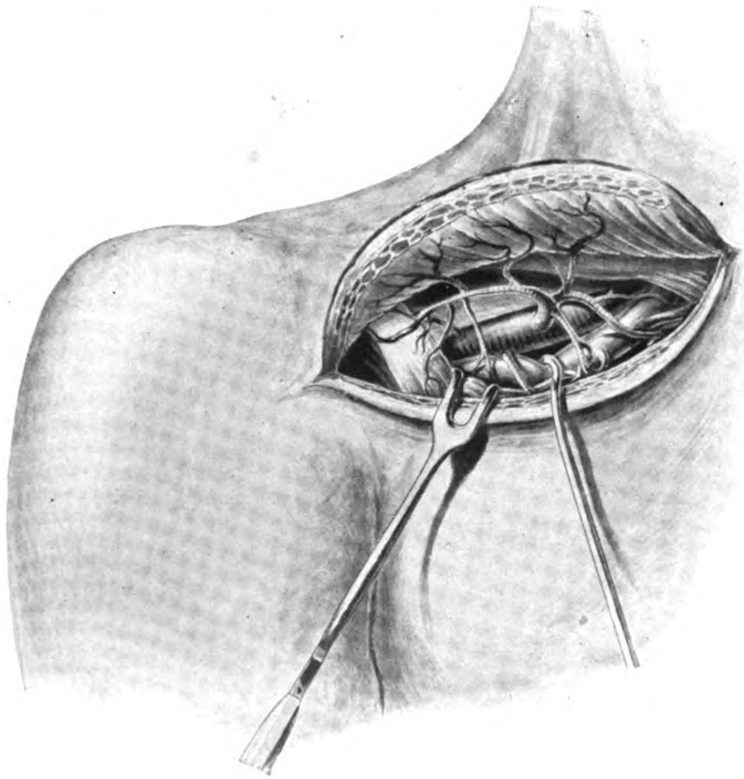


FIG. 204. THE FIRST PART OF THE AXILLARY ARTERY. The vessel has been exposed by the incision described in the text. The retractor pulls down the pectoralis minor and the blunt hook depresses the vein and exposes the artery.

thoracic vessels, which serve as useful guides to the artery, should not be injured; the wound is deepened at the outer end of the incision with great care, until the situation of these structures is evident.

When all hæmorrhage has been stopped, the loose cellular tissue beneath the pectoralis major is opened up, and the upper or inner border of the pectoralis minor is defined and pulled downwards with a broad retractor. This exposes the costo-coracoid membrane (coraco-clavicular fascia), which should be divided by a horizontal incision near the coracoid process; the axillary vein which bulges up into the wound with the movements of respiration must be carefully avoided in doing this. At this stage of the operation it will be well to bring the arm to the side and

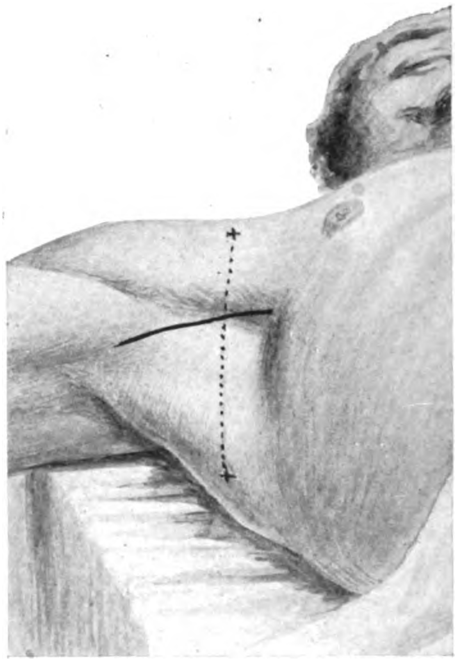


FIG. 205. INCISION FOR LIGATURE OF THE THIRD PART OF THE AXILLARY ARTERY. The upper + is on the margin of the anterior fold of the axilla, the lower one on the posterior fold.

pull down the shoulder firmly; this draws the vein away from the front of the artery and improves the view.

The operator is now working near the base of the coracoid process, and will find it advisable to use an electric forehead-lamp or a suitable head-mirror. Large reflecting retractors should be inserted into the wound, which requires frequent sponging, as there is often troublesome oozing from numerous small vessels; adrenalin solution (1 in 1,000) dropped into the wound will be helpful in checking this. The finger introduced into the wound feels the artery pulsating, and the vein can be seen expanding and contracting with respiration and hiding the artery. Above, and to the outer side of the artery, and somewhat superficial to it, lie the thick cords of the brachial plexus, which can hardly be mistaken even in the dead subject (see Fig. 204). The vein and the plexus are both more superficial than the artery and together hide it completely. The vein is therefore pushed gently downwards with a blunt spatula, whilst the brachial plexus is pulled upwards with a blunt hook. The sheath of the artery is then opened, and the needle insinuated round the

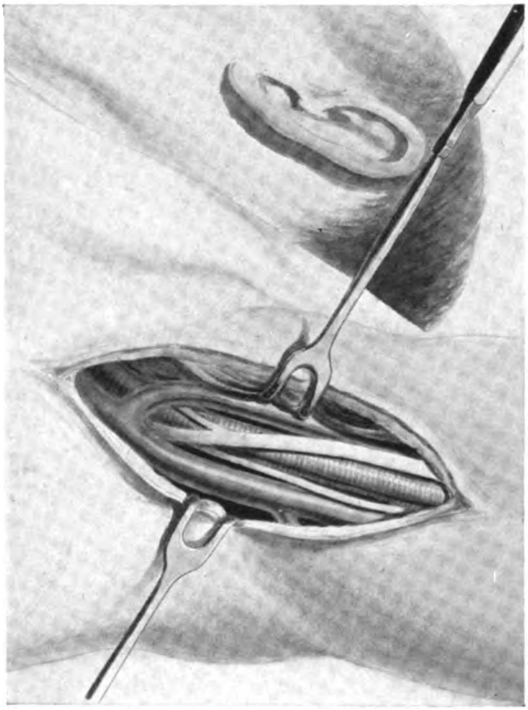


FIG. 206. THE THIRD PART OF THE AXILLARY ARTERY. The median nerve and its two heads are seen, also the internal (medial antebrachial) cutaneous nerve between the artery and vein. The ulnar nerve is not seen.

vessel. This is often very difficult, as the artery is deep down at the bottom of the wound; aneurysm needles with varying curves should be at hand, and it is very useful to have a flexible one which can be bent to any desired curve. The needle is best passed from below upwards, *i.e.* between the artery and the vein, as the latter structure is difficult to keep out of the way otherwise, whilst the brachial plexus can be protected from injury by the tip of the finger or a fine spatula. The acromio-thoracic (thoraco-acromial) artery must be preserved from injury throughout the operation.

LIGATURE OF THE THIRD PART

This operation is similar to ligature of the brachial artery; indeed, at examinations the ligature is often applied to the upper part of the brachial in mistake for the third part of the axillary. The positions of the limb and of the surgeon are the same as for ligature of the brachial (see p. 485). A horizontal incision about three inches long is made along the line of the artery at the junction of the upper with the middle third of the perpendicular let fall from the anterior to the posterior fold of the axilla; this corresponds to the inner border of the coraco-brachialis muscle (see Fig. 205). After the deep fascia has been divided, the inner edge of the coraco-brachialis muscle is identified and drawn upwards along with the musculo-cutaneous nerve. The artery should now be felt at once with the median nerve on its outer side; the latter structure should be drawn upwards with a blunt hook. The vein is seen in front of and below the artery, and is gently drawn down with another hook, when the ulnar nerve will be seen between the two (see Fig. 206). The needle is then passed round the artery generally from below upwards.

CHAPTER XII

LIGATURE OF THE ARTERIES OF THE NECK

LIGATURE OF THE INNOMINATE ARTERY

THIS operation is fraught with considerable danger, although hitherto the results have been more satisfactory than those of ligature of the first part of the subclavian. The chief danger in each case is death from secondary hæmorrhage, due to the proximity of the ligature to the heart. Moreover, this particular operation is beset with grave anatomical obstacles; the deep situation of the vessel and the number and importance of the structures in its immediate vicinity are calculated to tax to the utmost the skill and resource of even the boldest operator. When the patient is spare, and there is only slight venous engorgement, the operation, if performed carefully and methodically, does not present any insuperable difficulty; on the other hand, should the opposite conditions exist, the greatest care and skill may be unavailing, and the patient may either die of hæmorrhage on the table or the surgeon may be forced to abandon the operation.

Indications. The operation will only be required for an *aneurysm* involving either the first part of the common carotid trunk, or the first or second part of the right subclavian. A wound of such an important vessel as the innominate could hardly fail to prove fatal before assistance could be obtained. For an aortic aneurysm distal ligature of the carotid and subclavian would be done, as the affection would be almost certain to involve the root of the innominate.

Surgical anatomy. The artery extends from the arch of the aorta to the upper limit of the right sterno-clavicular articulation, and is nearly two inches long. It runs upwards, forwards, and outwards in the superior mediastinum. *Behind,* it lies upon the trachea below and the right pleura above. *In front,* the left innominate vein crosses the artery near its orign, and higher up it is separated by the sterno-thyreoid muscle from the sterno-hyoid and the right sterno-clavicular joint. The artery is overlapped by the right pleura, in front of which are the remains of the thymus and the manubrium sterni. It is also crossed obliquely by the inferior thyreoid veins. *On the right* of the artery are the upper part of the superior vena cava and the right innominate vein, the right vagus and the pleura. *On the left* side are the first part of the left common carotid and some of the inferior thryreoid veins below, and the trachea higher up.

Operation. (*a*) *Through a ⅄-shaped incision.* The position of the patient is the same as for ligature of the subclavian (see p. 503). The surgeon stands on the right side facing the head and makes an angular incision, one limb of which follows the inner margin of the sterno-mastoid, and the other runs horizontally along the clavicle on the right side; each limb of this incision is about three inches long. The skin and fascia forming this triangular flap are dissected up, and the origin of the sterno-mastoid is exposed and divided throughout its whole length about an inch above the clavicle, so as to enable the divided ends to be sutured together at the end of the operation. The anterior jugular vein, which opens into the external jugular just before the junction of the latter with the subclavian, will probably require ligature and division. Beneath the sterno-mastoid are the sterno-hyoid and sterno-thyreoid muscles. The sterno-hyoid and, if necessary, the sterno-thyreoid are drawn aside or divided, and the bifurcation of the innominate is thereby exposed.

Up to this point the operation is fairly easy, but in proceeding with its further steps the most serious difficulties may be encountered. Should the patient be thin and the innominate of full length, it may be fairly easy to place a ligature upon its trunk, owing to the comparatively high level of the bifurcation in the neck. Should the innominate be short, however, the bifurcation may be well down behind the sterno-clavicular articulation, and it will be impossible to pass the needle below it without obtaining more room. A similar difficulty may arise if the patient be very fat or the neck short and thick. In these very embarrassing cases it is now the rule to remove the upper portion of the sternum and the adjacent sterno-clavicular articulation. This is an excellent plan which only prolongs the operation by a few minutes, whilst no important structures are endangered, and the after-results are good. In order to carry it out, the soft parts should be carefully peeled off the back of the manubrium sterni with a periosteum detacher, and then the operator removes a rectangular portion of bone from the centre of the sternal notch to about the centre of the sterno-clavicular articulation with a suitable chisel, saw, or cutting-pliers. There is no objection to removing the articular end of the clavicle at the same time if more room is desirable (see Fig. 207). This procedure exposes the innominate trunk and renders it accessible to ligature, and is an improvement strongly to be recommended whenever the surgeon has the least difficulty in effecting his purpose by the ordinary method. It has been recommended as a means of bringing the innominate into reach, to pass a temporary ligature round the lower end of the common carotid, and to pull the innominate more up into the neck by traction upon this; this is a dangerous method, however, and is not so efficacious as removal of the bone.

When the artery has been exposed, the left innominate vein must be

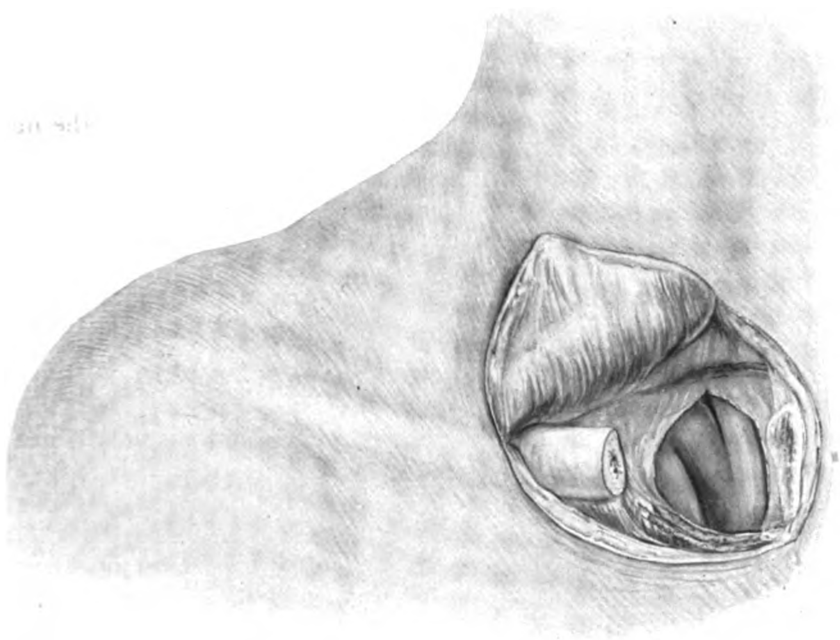


FIG. 207. LIGATURE OF THE INNOMINATE ARTERY. Parts of the sternum and the clavicle have been removed. The cut muscles are seen, also the innominate vein to the left and in front of the bifurcation of the artery.

pushed down out of the way with a fine flat, broad spatula, so that the sheath of the artery can be opened and the vessel cleared. It is always difficult to pass the needle round the artery, and the surgeon should be furnished with a series of needles with different curves and at different angles. The needle should be passed from the outer (or right-hand) side, and the ligature should be a double one of floss silk tied in a 'stay-knot' (see p. 420), and only drawn tight enough to cause apposition of the arterial walls without dividing them.

The divided muscles are sutured, and the skin is united by a continuous suture; it is well, however, to insert a small drainage tube for forty-eight hours in order to drain the large cavity left after the operation.

(*b*) *Through a median vertical incision.* Mr. Walter Spencer has suggested the employment of a median vertical incision for ligature of this vessel, on the ground that, as no muscles are divided, the parts will fall together sufficiently well after the operation to obviate the necessity for a drainage tube, a point of some importance considering the extreme danger of sepsis as a cause of secondary hæmorrhage. There is no doubt that the parts do come together better with this incision, and therefore the need for drainage is not so great, but it is more difficult to get at the innominate through this incision, and it may be necessary to remove bone in order to do so (*vide supra*). On the whole, the old angular incision probably gives more satisfactory access than the median one. At the present time, moreover, the risk of sepsis is so slight that it can no longer be an important factor in determining which method should be employed.

LIGATURE OF THE SUBCLAVIAN ARTERY

Indications. (i) For certain cases of *axillary aneurysm.* The operation will take the form of proximal ligature.

(ii) For some cases of *innominate or aortic aneurysm.* Here the operation will take the form of distal ligature.

(iii) For a few cases of *aneurysm of the first part of the axillary artery* not encroaching upon the third part of the subclavian. The operation is only possible when the aneurysm is small.

(iv) For *wounds of the subclavian,* generally stabs. Operation here is rarely of avail, as the patient usually dies before assistance can be obtained.

(v) *As a preliminary to removal of the entire upper extremity* (see p. 268).

(vi) *To secure hæmostasis* in amputations of the upper limb or in removal of large growths about the axilla or scapula. In these cases a temporary ligature only will be used.

Surgical anatomy. On the right side the artery commences at the bifurcation of the innominate artery behind the right sterno-clavicular articulation. On the left side it arises from the aorta behind the lower part of the manubrium sterni. The left subclavian is, therefore, longer than the right, measuring nearly four inches as against three, and lies both at the base of the posterior triangle and in the upper part of the superior mediastinum. The relations of the second and third parts are similar on the two sides; those of the first parts differ widely.

Relations of the first part of the right subclavian. *Behind* the artery are the recurrent laryngeal and the sympathetic nerves and the dome of the pleura. Deeper still are the transverse processes of the last cervical and first dorsal vertebræ, and the longus colli muscle.

In front of it are the right vagus, the phrenic, and branches of the sympathetic, the internal jugular and the vertebral veins, whilst still more superficially are the sterno-hyoid and sterno-thyreoid muscles, the anterior jugular vein, the sternal end of the clavicle and its ligaments, and the sterno-mastoid muscles.

Below, the recurrent laryngeal nerve passes between the artery and the top of the pleura. The subclavian vein is below and superficial or anterior to the artery.

Relations of the first part of the left subclavian. This portion is almost vertical. *Behind* it are the left margin of the œsophagus, the thoracic duct, the inferior cervical ganglion, and the longus colli muscle.

In front, and to the right of the artery, lie the left vagus and its inferior cardiac branch, the superior cardiac branch of the sympathetic, the phrenic, and the left common carotid artery. The left innominate vein crosses it obliquely below, as do also the internal jugular, vertebral, and subclavian veins above. The left vagus runs down the inner side of the artery but crosses its anterior surface below. Its left side is overlapped to some extent by the left lung and pleura, the sterno-hyoid, sterno-thyreoid, and sterno-mastoid muscles. *Internal* to it are the thoracic duct, the œsophagus, the left recurrent laryngeal nerve, and the trachea. *External* to it is the left pleura.

Relations of the second and third parts of the artery. These portions of the artery lie at the root of the neck reaching outwards over the top of the lung, and passing behind the scalenus anticus (anterior) muscle. The second part of the artery lies entirely behind the scalenus, whilst the third part extends from the outer border of that muscle to the outer border of the first rib.

Behind and below, the second part of the artery is in close apposition to the pleura, while the third part of the artery rests upon the upper surface of the first rib. *In front,* the second part is covered by the scalenus anticus (anterior) and the sterno-mastoid muscles, the former of which separates it from the subclavian vein (which lies on a slightly lower level), from the transverse cervical and suprascapular (transverse scapular) arteries, from the anterior jugular vein, and, on the right side, from the phrenic nerve. *In front* of the third part and on a slightly lower level lies the subclavian vein, to join which the external jugular crosses the artery towards its inner end and there receives the transverse cervical and suprascapular (transverse scapular) veins, which are, therefore, superficial to the artery. The nerve to the subclavius muscle crosses the artery, and, with the clavicle, is also an anterior relation of the vessel; the artery is also covered by the deep cervical fascia, the clavicular branches of the descending cervical nerves, the platysma and the skin. *Above*, and to the other side of the artery, lies the lowest cord of the brachial plexus.

The first part of the artery is but rarely tied, the operation having proved almost uniformly fatal. It would appear that the fatality of the operation is not likely to be greatly diminished in the immediate future, as death usually takes place from secondary hæmorrhage due to giving way of the coats of the vessel even in an aseptic wound. The operation will, however, be described, as it is not infrequently set for examination purposes.

The operation for ligature of the third part of the subclavian is the one usually performed. The second part of the artery is practically never tied, except in some few cases where after exposure the third portion has been found involved in the aneurysm, so that the vessel has to be traced further up, and the ligature applied to the second part.

LIGATURE OF THE FIRST PART OF THE RIGHT SUBCLAVIAN

This operation is not only difficult to perform, but it has hitherto been followed with indifferent success. It is difficult to say how much better results may be looked for in the future, owing to the improvements in wound-treatment and the use of non-irritating ligatures, but it seems certain that there must always be a serious risk of secondary hæmorrhage, owing to the proximity of the seat of ligature to the heart, and the great force which the walls of the vessel have to withstand, and which they are so often unable to bear when damaged by the ligature. The operation is never attempted upon the left side, except as a dissecting-room exercise, but it is feasible upon the right side, and in that situation must be looked upon as a recognized operation notwithstanding the condemnation passed upon it by writers reviewing results due, to a large extent, to faulty technique.

Blake (*Annals of Surgery*, 1906, vol. xliii, p. 919) gives the notes of a very interesting case of an aneurysm of the second and third parts of the right subclavian successfully treated by combined ligature of the first part of the subclavian artery and the first part of the axillary. The first part of the subclavian was exposed by the method detailed below (see p. 501), and a ligature was successfully applied to it. The wound healed perfectly, but the pulsation never completely ceased in the aneurysm and began to get worse, so that a month later the first part of the axillary was exposed by an incision between the deltoid and pectoralis fibres, and a ligature applied to it as near the subclavian as possible; this resulted in complete cure of the aneurysm. When the number and size of the branches given off by the first and second portions of the artery are considered, and the freedom with which they anastomose, this would appear to be the only rational method from which to expect a permanent cure of an aneurysm in this situation. The risk to the circulation in the upper extremity is very slight indeed, and if the treatment be undertaken in two stages, as in this case, no harm is likely to happen; indeed it is questionable if gangrene would ever be likely to occur provided that the wound were kept aseptic.

Pack (*ibid.*, p. 930) recorded a similar operation for the cure of traumatic aneurysm of the thyreoid axis. This also was successful, and only differed from the preceding case in that the second ligature, instead of being placed at the junction of the axillary with the subclavian, was placed on the latter vessel just external to the scalenus anticus.

The mortality of this operation is said by Lilienthal (*Annals of Surgery*, 1906, vol. xliii, p. 921) to have fallen since 1890 from 75% to 16%. No doubt some part of this diminution is due to improved aseptic methods, but there is little doubt in the minds of most observers that it is also partly due to the absence of secondary hæmorrhage from direct irritation of the ligature as a result of the use of approximation ligatures; the adoption of the 'stay-knot' of Ballance and Edmunds (see p. 419) has to some extent contributed to this result.

Indications. These will be practically identical with those for ligature of the third part.

Operation. The positions of the patient and the surgeon are the same as for ligature of the innominate. The surgeon has the choice of two incisions for exposure of the vessel:—

(*a*) *An oblique incision* about four inches long parallel to and about half an inch external to the anterior margin of the sterno-mastoid, and extending well down on to the clavicle. As this incision is deepened, the interval between the two heads of the sterno-mastoid is reached, and this is enlarged upwards by splitting the fibres of the muscle so as to enable the two heads of the muscle to be sufficiently retracted to opposite sides to give proper access to the vessel. The remaining steps of the operation are the same as in the Δ-shaped incision (*vide infra*).

This oblique incision possesses the *advantage* that the parts fall together well after the operation, and leave no large cavity requiring drainage—an important consideration in these cases. It has the *dis-*

advantage, however, that it hardly gives enough room, except in thin subjects in whom the sterno-mastoid is comparatively small; it should therefore be reserved for them.

(*b*) *An* ⅃*-shaped incision* is the more usual one; one limb lies over the anterior margin of the sterno-mastoid, and the other horizontally along the clavicle. The triangular flap thus formed is dissected up, and the sterno-mastoid is divided horizontally about half an inch above its origin so as to leave enough of the latter for the fibres to be reunited at the end of the operation. In doing this the anterior jugular vein will probably be divided. The sterno-thyreoid muscle covers the artery and must either be pulled aside or divided, and, if necessary, a portion of the outer edge of the sterno-hyoid must be similarly treated. This brings the great vessels of the neck into view, and the bifurcation of the innominate can be detected by the finger.

The chief sources of difficulty met with at this stage are the large venous trunks in front of the artery, which vary in size with respiration, and seriously impede the operation. They should be cautiously peeled down and pushed out of the way, a few light touches with the point of a sharp knife being required to loosen the delicate cellular tissue which connects them to the arteries. They are then held down out of the way by a fine thin narrow spatula, and the sheath of the innominate artery is opened quite close to its bifurcation. The subclavian is then traced from this point outwards beyond the bifurcation, and the needle is insinuated round it from below upwards, as in that way the vein and the pleura are best avoided. During this procedure the termination of the internal jugular vein will have to be pulled to the outer side with the finger or a small spatula; with it should go the vagus.

It is usually recommended that the vertebral should be tied (see p. 518) simultaneously with the first part of the subclavian. At this stage of the operation it is somewhat less difficult than under ordinary circumstances, owing to the free exposure of the parts, but it would be impossible if the operation were being done for aneurysm of the second part of the subclavian. A point that must not be forgotten is that the subclavian comes off at a very acute angle, and not almost horizontally as one would suppose. It ascends almost vertically from behind the carotid, and the angle between these two arteries is quite small.

Perusal of the cases quoted by Blake and Pack (*loc. cit.*) makes one consider seriously the question of applying a ligature simultaneously to the third part of the subclavian, or the first part of the axillary in cases of aneurysm of the second or third part of the artery.

LIGATURE OF THE THIRD PART

Operation. A pillow is placed beneath the shoulder on the affected side, the head is turned to the opposite side, the neck moderately extended, and the arm drawn firmly downwards so as to depress the clavicle and thus open up the posterior triangle as much as possible. The surgeon stands on the affected side facing the patient, and, drawing down the skin over the clavicle with his left hand as far as it will come, makes an

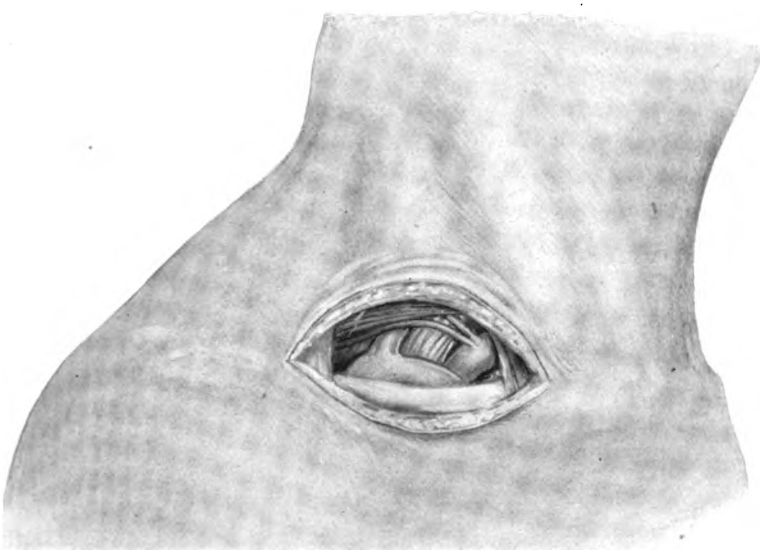


FIG. 208. LIGATURE OF THE THIRD PART OF THE SUBCLAVIAN. The artery and its branches, which in this case arise from the beginning of the third part instead of the second, as is usually the case, are seen below the last cord of the plexus. The subclavian vein is receiving the external jugular; both were unduly large in the subject from which the drawing was made.

incision three inches in length down to that bone between the adjacent margins of the sterno-mastoid and the trapezius muscles. The skin is pulled down in order to avoid injury to the external jugular vein, which pierces the deep fascia immediately above the clavicle; as this spot is fixed, it is impossible to draw it down with the skin, and therefore the vein cannot be injured in the first incision. After the skin has been allowed to retract, the incision crosses the root of the posterior triangle transversely a little more than an inch above the clavicle.

The position of the external jugular vein is now defined, the deep fascia is opened up throughout the length of the incision, and a little dissection reveals the posterior belly of the omo-hyoid muscle, the lower margin of which is defined and drawn up with a retractor. The base of the posterior triangle is thus displayed, and the finger introduced into it will at once feel the cords of the brachial plexus, which run from above obliquely downwards and outwards; they are the best guide to the artery. The outer border of the anterior scalene and the scalene tubercle, which are mentioned by most writers as the best guides to the artery, are often wholly unreliable. In the dead subject, at any rate, it may be difficult to identify the outer border of the scalene muscle, and equally difficult to identify the tubercle, while the cords of the plexus can never be mistaken, at any rate when the posterior triangle has been well opened up. There is often considerable oozing from the numerous veins in the posterior triangle; these should be tied as they are injured, but it is important to avoid injuring the corresponding arteries; the latter run nearly parallel with the main vessel, and so it is easy to avoid injuring them.

When the lowest cord of the plexus has been identified by clearing it with a few light touches of the knife, it is hooked up out of the way. The artery lies parallel with it, below it and on a slightly deeper plane. As a rule the vein does not come into view unless respiration be obstructed, as it lies below the artery and is separated from it by the scalenus anticus (anterior) muscle. When the artery has been identified, its sheath is opened and the vessel cleared, particular care being taken to avoid puncturing the pleura, which lies below the artery. It will be found safest to pass the needle from below upwards, so as to avoid damage to the pleura and the vein; it is easy to avoid including the lowest cord of the plexus in the ligature by pressing it back out of the way with the finger, or with a dissector. The ligature should be made to approximate the coats of the artery and not to divide them. The wound is sutured without a drainage tube, and the arm is fastened to the side for a week or ten days.

Difficulties and dangers. These should be few if the above recommendations be followed. The principal difficulty will occur from the matting together of the tissues in the posterior triangle when the sac of the aneurysm encroaches upon it. This is likely to cause troublesome oozing, which is best dealt with by tying each bleeding point as it is met with, and by not using blunt dissectors or any tearing instruments, as they only cause infiltration of the areolar tissue with blood, and obscure the view. The artery is easy to find if the brachial plexus be taken as a guide. This prominent structure can be actually felt through the skin in a thin subject, and can hardly be mistaken when the posterior triangle has been opened up. The chief difficulty in the operation lies in clearing the artery and in passing the needle without damaging the pleura. This can only be avoided by care and gentleness, pulling down the shoulder as far as it will go, and using needles of different curves.

LIGATURE OF THE COMMON CAROTID ARTERY

Indications. (i) For *wounds of the vessel itself.* These will be chiefly stabs or gunshot wounds. When the artery is damaged in cut-throat, death usually occurs before assistance can be obtained.

(ii) For *aneurysm of the carotid trunk or its main branches.* This affection is more frequent in the common trunk than in either of its terminal branches. The ligature will be applied on the proximal side of the aneurysm, and if it be applied for aneurysm of the common trunk the external carotid may be ligatured simultaneously (see p. 513) in order to prevent recurrence of the pulsation through this freely anastomosing vessel.

(iii) For *aneurysm of the innominate or the aorta.* Here the distal operation is performed, and, as a rule, the subclavian artery will be tied simultaneously.

(iv) For *aneurysm of the orbit.* The operation has been performed several times for this condition, and has succeeded in some instances; it is by no means invariably successful, however.

(v) A *temporary ligature* is not infrequently passed around the common carotid trunk to control the bleeding during removal of large tumours from the side of the head or face, or during removal of very vascular tumours of the jaws. A better plan is to apply the compression to the external carotid only. Instead of a ligature, Crile's artery compressors may be used (see p. 379).

(vi) The common carotid has also been tied for the *control of hæmorrhage* due to various conditions, such as cancer of the tongue or face, profuse bleeding after removal of the tonsil or the opening of a tonsillar abscess; but a better plan is to tie the external carotid trunk either on one or both sides, as the cerebral symptoms due to the scanty blood-supply via the internal carotid are not then met with. The same remark applies to ligature of the common carotid when performed for the cure of aneurysm by anastomosis.

Surgical anatomy. The right common carotid artery extends from the right sterno-clavicular articulation to the level of the upper border of the thyreoid cartilage, where it divides into its external and internal branches. The left trunk arises from the arch of the aorta, but terminates at a similar point and is therefore longer than its fellow.

The relations of the two in the neck are similar; the left common carotid has intra-thoracic relations in addition.

Relations of the left common carotid in the thorax. The intra-thoracic part of this artery measures from one to one and a half inches in length, and passes upwards and slightly outwards through the superior mediastinum on a plane posterior to the innominate trunk; it is therefore more overlapped by the pleura.

Posteriorly, the vessel lies upon the trachea, the left recurrent laryngeal nerve, the œsophagus and the thoracic duct.

In front, the left innominate vein crosses the artery obliquely, while the cardiac branches of the left vagus and sympathetic cross it vertically. Superficial to these are the remains of the thymus and the anterior margins of the left lung and pleura, in front of which again lies the manubrium sterni with the origin of the sterno-hyoid and sterno-thyreoid muscles.

On the right side are the innominate artery below, and the trachea and the inferior thyreoid veins higher up.

On the left side, the left pleura is in close contact with the artery. Somewhat posteriorly are the left phrenic and vagus nerves and the left subclavian artery.

Relations of the common carotid in the neck. This portion of the vessel is about three and a half inches long and runs upwards, outwards, and backwards in the anterior triangle of the neck. It diverges somewhat from its fellow on the opposite side, being separated from it below by the trachea and œsophagus and above by the much wider pharynx. The artery is enclosed in a special sheath of deep cervical fascia called the carotid sheath, together with the internal jugular vein and the vagus nerve.

Behind, the vessel lies from above downwards upon the rectus capitis anticus major (longus capitis), the longus colli, and the scalenus anterior, upon which are the prevertebral fascia and the cords of the cervical sympathetic nerve. Just below the level of the cricoid cartilage the inferior thyreoid artery passes behind the vessel, whilst lower down the vessel lies over the vertebral artery and the thoracic duct; the vagus lies behind and to its outer side.

In front, the descendens hypoglossi nerve lies on the sheath of the artery, but is sometimes enclosed within it. The artery is crossed by the omo-hyoid muscle and the sterno-mastoid branch of the superior thyreoid artery, and by the superior and middle thyreoid and generally also by the lingual veins. Above the omo-hyoid the vessel is overlapped by the anterior margin of the sterno-mastoid, whilst below that muscle it is also covered by the sterno-thyreoid and sterno-hyoid muscles, and frequently also by the lateral lobe of the thyreoid body. The communicating vein between the facial and anterior jugular lies along the anterior margin of the sterno-mastoid, and hence crosses the line of the artery obliquely. The anterior jugular vein is also in front of the artery just above the sternum, but the sterno-hyoid and the sterno-mastoid muscles intervene between these two structures.

On the inner side below lie the trachea and the œsophagus with the recurrent laryngeal in the angle between them, also the lateral lobe of the thyreoid body and the inferior thyreoid vessels, whilst above are the larynx and the pharynx.

On the outer side lie the internal jugular vein, which overlaps the lower end of the artery in front, especially on the left side, and the vagus nerve.

Line of the artery. From the sterno-clavicular articulation to the mid-point between the angle of the jaw and the mastoid process. The bifurcation of the carotid corresponds to a point along this line opposite the upper border of the thyreoid cartilage. The line of the artery corresponds fairly closely with the anterior margin of the sterno-mastoid when the head is turned slightly to the opposite side.

The carotid is tied either above or below the omo-hyoid according to the position of the ligature relative to this structure. The former operation is easier and is therefore more frequently done, the operation being known as ligature of the common carotid at ' the seat of election '. The artery is much more deeply placed below the omo-hyoid, and the operation for its ligature is proportionately more difficult.

LIGATURE ABOVE THE OMO-HYOID

Operation. The parts are shaved, a small pillow is placed beneath the shoulder on the affected side, the neck is slightly extended, and the chin is turned to the opposite side. The surgeon stands on the affected side and makes an incision (see Fig. 209) three inches long in the line of the artery (*vide supra*), with its centre opposite the cricoid cartilage. This incision divides the platysma and the superficial fascia and will probably also divide the communicating vein between the facial and the anterior jugular, and will expose the inner margin of the sterno-mastoid enclosed in its sheath of deep cervical fascia. The deep cervical fascia is next incised throughout the length of the incision just anterior to the margin of the muscle, which is drawn back in its sheath with suitable retractors. This opens up the anterior triangle of the neck and exposes the omo-hyoid muscle crossing the artery obliquely from below upwards and inwards; its upper border is defined by a few touches of the knife and the muscle is pulled downwards. In doing this it will probably be necessary to tie the middle thyreoid vein as it crosses the field of operation; the sterno-mastoid artery may also be divided. The lateral lobe of the thyreoid does not usually give trouble; should it be enlarged, it must be pulled to the inner side. In the dead subject it may cause confusion, and may be mistaken for the omo-hyoid or some of the laryngeal muscles. The absence of definite fibres will demonstrate the mistake.

The internal jugular vein will now be seen, and, in the living subject, the artery will be felt pulsating just internal to it. In the dead subject the vein offers no hindrance to the operator; in the living, however, it is

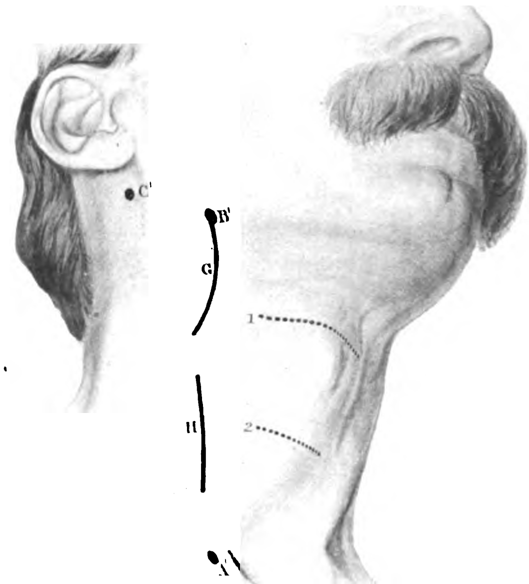


FIG. 209. INCISIONS FOR LIGATURE OF THE COMMON AND EXTERNAL CAROTID ARTERIES. A' is on the sterno-clavicular articulation, C' on the tip of the mastoid process, and B' on the angle of the jaw. The dotted line 1 is the level of the upper border of the thyreoid cartilage, 2 that of the cricoid. H is the incision for ligature of the common carotid above the omo-hyoid, G that for ligature of the external carotid.

often in the way, owing to its variation in size during respiration, and special care has to be taken to avoid damaging it when opening the sheath of the artery. The sheath, along which will be seen the descendens hypoglossi nerve (see Fig. 210), is opened to the inner side, and in clearing the vessel care must be taken to keep the point of the needle closely in contact with the vessel wall behind so as to avoid including the vagus in the ligature. The methods of clearing the artery and passing the needle have already been described (see p. 418), and the details there given apply to this vessel, and should be followed scrupulously. If the sterno-mastoid be unduly large, or the neck be fat and thick, the head should be bent forwards by an assistant so as to relax the muscles while the artery is being cleared and the ligature passed; the latter should be tied so as to divide the inner and middle coats.

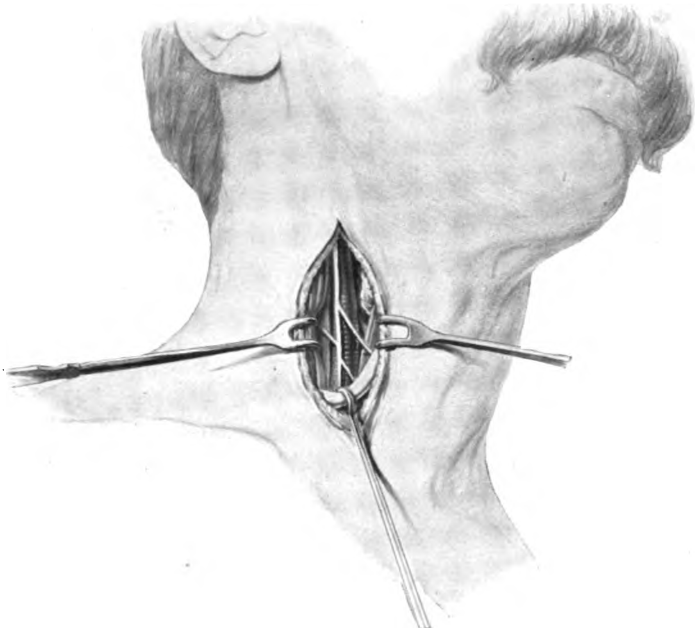


FIG. 210. LIGATURE OF THE COMMON CAROTID ABOVE THE OMO-HYOID. The omo-hyoid is hooked downwards and the artery is seen with the vein external to it and the descendens hypoglossi nerve on its sheath.

LIGATURE BELOW THE OMO-HYOID

Operation. The positions of patient and operator are the same as before. The incision (see Fig. 211), which should be about three and a half inches long, reaches from the cricoid cartilage to the sterno-clavicular joint, following the line of the artery given above (see p. 507). The inner margin of the sterno-mastoid is exposed, and the deep cervical fascia in front of it is incised so as to allow the muscle to be pulled back in its sheath. This may be very difficult in stout subjects with well-developed muscles, and it may therefore be necessary to detach the sterno-mastoid partially from the clavicle. This will expose the sterno-thyreoid and possibly the sterno-hyoid muscles, which should be pulled inwards, whilst the omo-hyoid, which lies more externally, should have its lower border defined and hooked upwards and outwards (see Fig. 212). At this stage there may be severe oozing from the anterior jugular and the inferior thyreoid veins, which may all require ligature and division. When the muscles have been retracted, the artery can be felt

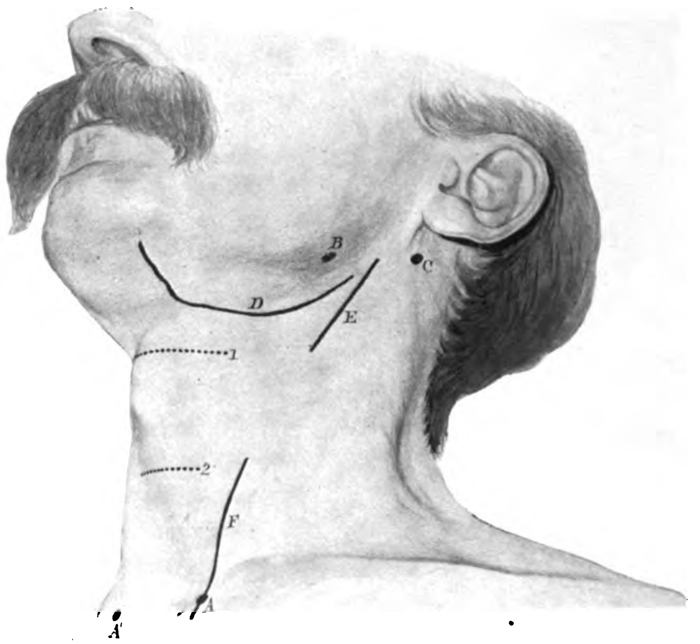


FIG. 211. INCISIONS FOR LIGATURE OF THE COMMON AND INTERNAL CAROTID AND THE LINGUAL ARTERIES. A is on the sterno-clavicular joint, B on the angle of the jaw, and C on the tip of the mastoid process. The dotted line 1 denotes the level of the upper border of the thyreoid cartilage, 2 that of the cricoid. F is the incision for ligature of the common carotid below the omo-hyoid, E that for the internal carotid, while D is the incision for ligature of the lingual.

pulsating at the bottom of the wound. It is here that the chief difficulty will be met with, as the distended internal jugular vein gets in the way and greatly interferes with the process of opening the sheath and clearing the artery. This is especially the case on the left side, where the distended vein may actually lie in front of the artery during expiration. On the right side there is generally an interval between the two, and the vein only comes into close relation with the artery when it is distended to the utmost. The vein will probably have to be held back by a narrow flat spatula or by the surgeon's fingers, as its walls are delicate and are easily punctured by the aneurysm needle. A wound of the vein in this situation is a very dangerous matter (*vide infra*).

Difficulties and dangers. These are very few, especially when the artery is being tied above the omo-hyoid. If the chin be turned

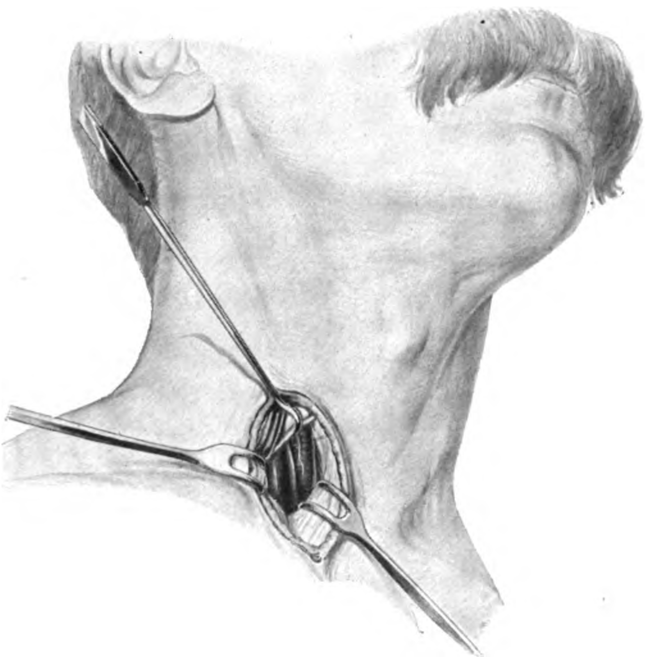


FIG. 212. LIGATURE OF THE COMMON CAROTID BELOW THE OMO-HYOID. The omo-hyoid is hooked up, showing the artery and the very large internal jugular vein.

too far to the opposite side, the incision may be made over the sterno-mastoid muscle, instead of along its anterior margin, and the operator may therefore be delayed by having to search for this landmark. Moreover, such an incision renders the proper retraction of the parts more difficult. Serious oozing from the thyreoid veins or an enlarged lateral lobe of the thyreoid will not be met with if care be taken to incise cleanly, and to pick up and tie bleeding points as they are met with. Troubles of this description are only likely to be met with when the parts are ruthlessly torn with blunt dissectors. The chief difficulty in tying the vessel in the dead subject comes from a misconception as to the depth at which the vessel lies. When the neck is rigid, as it generally is, and the head cannot be turned over to the opposite side, the artery lies much deeper than it does in the ordinary position.

Injury to the structures in the immediate vicinity of the artery is the chief risk in the operation of ligature below the omo-hyoid. Injury to the internal jugular vein may easily occur owing to the constant variation in size caused by respiration. The surest way to avoid injuring the vein is to press it well to the outer side with the finger, or else to define its inner edge by a few touches with the point of a sharp knife, and then pull the vein away from the artery and hold it out of danger with a blunt hook. The vein is not likely to be damaged during the passage of the needle round the artery, unless the sheath be insufficiently opened and undue force be employed. Should the vein be punctured, the hæmorrhage is profuse, and if the wound in it be large, and especially if it be seated below the omo-hyoid, air may be sucked into the vein. Immediately such an accident is recognized, pressure should be applied to the wound in the vein to occlude it and prevent further entry of air. The wound should then be flooded with sterilized salt solution, pressure applied on either side of the opening in the vein, and the rent in it seized with forceps and a lateral ligature applied. The artery should be cleared afresh and ligatured either above or below the spot at which the wound in the vein has occurred.

Inclusion of the vagus or sympathetic nerves in the ligature is not likely to happen unless undue force be used to get the needle round the artery. If the sheath be properly opened, the needle finds its way readily between the artery and the sheath, and, as the vagus and sympathetic lie outside and behind this structure, their inclusion in the ligature should be out of the question. In the dead subject there is considerably more difficulty in passing the needle owing to the rigidity and retraction of the parts.

The chief danger after ligature of the common carotid is the occurrence of cerebral complications due to defective blood-supply, which leads to a temporary abeyance of function, and may end in cerebral softening, coma, and death. In the minor cases the patient gets symptoms of cerebral anæmia, such as twitchings, giddiness, and temporary paralysis; whilst in the graver cases, gradually increasing coma ensues, followed by convulsions and death. It is owing to this serious complication that the mortality of the operation is still so comparatively high. The surgeon, therefore, should always tie the external carotid in preference to the common trunk when he has the choice.

LIGATURE OF THE EXTERNAL CAROTID ARTERY

Indications. (i) For *wounds.* These will be chiefly stabs in the parotid region. The artery is occasionally damaged in attempted cut-throat; here the lesion is generally immediately fatal.

(ii) For *persistent hæmorrhage from the tonsil.* For these cases ligature of the external carotid is distinctly preferable to ligature of the common trunk, as it is equally effective in arresting the bleeding, and there is no risk of cerebral complications.

(iii) For *aneurysm of the external carotid:* a very rare condition.

(iv) *Temporary ligature* of the external carotid may be very useful when removing growths in the parotid region or on the side of the face. Some surgeons tie the artery permanently under these circumstances, but it is quite sufficient to exercise a temporary compression of it so that the circulation can be controlled throughout the operation; when the tumour has been removed, the temporary compression is relaxed and the bleeding vessels are secured. This method of employing temporary compression is most valuable when the wound communicates with the mouth or pharynx, as secondary hæmorrhage is a frequent complication of permanent ligature of the external carotid under these circumstances; when only temporary compression of the vessel is employed during the operation and the terminal branches are secured at the end of it, this serious complication is not so likely to occur. Crile's compression clamp (see p. 379) may be used in place of a temporary ligature.

(v) The vessel is sometimes tied in order *to starve large malignant growths* involving the mouth, side of the face, parotid or jaw, which there is no possibility of removing successfully. The operation is done with the same object as ligature of the lingual for inoperable cancer of the tongue. It is not likely, however, to be followed with much success, as the anastomosis with the opposite side is very free. If done at all, the artery on the opposite side should be ligatured simultaneously.

(vi) For *persistent middle meningeal hæmorrhage.* As a rule even the worst bleeding from the middle meningeal may be arrested by plugging the foramen spinosum with Horsley's wax or some other suitable material after enlarging the wound in the skull sufficiently downwards. Occasionally, however, it may be necessary to tie the carotid.

(vii) For *aneurysm by anastomosis.* When the aneurysm is situated on the face and side of the head, the control of the blood-supply through the external carotid will greatly facilitate the other measures suitable for the treatment of this condition. If the aneurysm can be excised, it will suffice to exercise temporary compression of the carotid during the excision. The bleeding points can then be secured and the compression relaxed.

Surgical anatomy. *Behind,* the artery lies close to the internal carotid, which is superficial and posterior to it at the bifurcation. The two vessels are separated by the stylo-glossus and stylo-pharyngeus muscles, which pass behind the external trunk, as do also the glosso-pharyngeal nerve, the pharyngeal branch of the vagus, and the stylo-hyoid ligament. Higher up in the neck it is in relation with the parotid gland and the cartilaginous portion of the external auditory meatus.

In front, it is crossed by the various veins joining the internal jugular, namely, the lingual, common facial, and superior thyreoid. The hypoglossal nerve crosses the artery and turns inwards immediately below the origin of the occipital branch. The posterior belly of the digastric and the stylo-hyoid muscles also cross the artery, whilst more superficially it is overlapped by the anterior border of the sterno-mastoid below and the parotid gland above. In the latter structure the temporo-maxillary (common facial) vein descends on the outer side of the artery, and the facial nerve crosses it.

On its *inner side* it is in relation with the inferior constrictor near its commencement, but it is separated above from the pharynx by the stylo-pharyngeus and the stylo-glossus muscles, the glosso-pharyngeal nerve, and the pharyngeal branch of the vagus. The laryngeal branches of the superior laryngeal nerve also lie on its inner side.

The artery may be tied either above or below the posterior belly of the digastric, but it should always be exposed in the latter situation, if possible, on account of the danger of dividing the facial nerve in the incision for exposing the vessel above the digastric. If it be desired to apply the ligature above that muscle, therefore, the vessel should be exposed below it and traced upwards after the digastric has been displaced. The ligature is usually applied between the superior thyreoid and the lingual arteries—which vessels should also be tied simultaneously—and the seat of ligature is generally opposite the great cornu of the hyoid bone, which can be easily felt by the finger in the wound.

Operation. The positions of the patient and the surgeon are the same as in the preceding operation (see p. 507). An incision (see Fig. 209) two and a half inches long is made in the line of the artery from the angle of the jaw to the bifurcation of the common carotid (see p. 507). After the deep fascia has been divided, and the anterior triangle has been opened up, the sterno-mastoid is drawn well back, and the lower border of the posterior belly of the digastric is defined and pulled upwards. The vessel will then be exposed, as it passes beneath this muscle opposite the great cornu of the hyoid bone, which can be felt in the wound; if a further guide be necessary, identification of the hypoglossal nerve winding round the occipital artery will satisfy the surgeon that he is dealing with the external carotid. A little dissection is required to identify the vessels between which the ligature is to be placed. Of these the most constant in its direction is the superior thyreoid, which has a characteristic curve, at first upwards and then downwards and inwards (see Fig. 213). This vessel should be secured, and the carotid

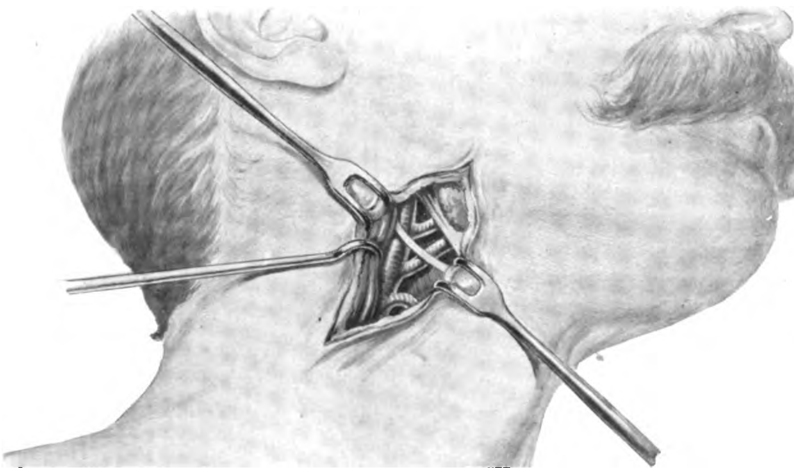


FIG. 213. LIGATURE OF THE EXTERNAL CAROTID ARTERY. The artery and its branches are seen, as is also the hypoglossal nerve and the posterior belly of the digastric.

is then cleared upwards to the next branch, namely, the lingual, which is secured in a similar manner. Finally the needle is passed round the external carotid trunk from without inwards; the facial and the ascending pharyngeal branches may with advantage be ligatured at the same time.

If it be desired to put a temporary ligature round the vessel, its branches are not secured. A ligature of silk, tape, or kangaroo tendon is passed round the vessel, its ends are knotted together to form a loop, by means of which traction is made so as to kink the artery acutely and obstruct the circulation through it. Crile's clamp (see p. 379) may be used instead of a ligature.

LIGATURE OF THE INTERNAL CAROTID ARTERY

Indications. This operation is very rarely done. It may be called for—

(i) For *wounds of the vessel,* which, however, are usually fatal before help can be obtained.

(ii) For *aneurysm of the internal carotid.* There will rarely be room, however, to apply a ligature to the internal carotid below an aneurysm of that vessel. In very small aneurysms, however, it is possible that advantage might be taken of the fact that the internal carotid gives off no branches in the neck to expose and tie the vessel above and below the aneurysm, and either incise the aneurysm and turn out the clot, or excise the sac completely.

(iii) For *orbital aneurysm.* Since this condition is supposed to be due to a communication between the internal carotid and the cavernous sinus, ligature of the internal carotid would be a better method of treatment than ligature of the common trunk. I have treated two such cases successfully (one after previous unsuccessful ligation of the common carotid) by combined ligature of the internal carotid and the angular vein (see *Ophthal. Soc. Trans.,* 1907).

Surgical anatomy. The line of the artery is a continuation upwards of that of the common carotid trunk (see p. 507). The vessel extends from the upper border of the thyreoid cartilage to the anterior clinoid process of the sphenoid, traversing the carotid canal in the temporal bone. In the neck it lies at first behind and to the outer side of the external branch, but it gets to its inner side as it passes beneath the posterior belly of the digastric; it then ascends under cover of the parotid gland to the carotid canal.

Relations. *Behind,* it lies upon the rectus capitis anticus major (longus capitis), with the prevertebral fascia, the superior cervical ganglion, and the cords of the sympathetic and the vagus nerve. Just as it is about to enter the skull through the carotid canal, the hypoglossal, the vagus, the glosso-pharyngeal, and the spinal accessory nerves pass behind it and separate it from the internal jugular vein.

In front are the sterno-mastoid, with the platysma and the deep cervical fascia, and the posterior belly of the digastric and the stylo-hyoid, and the deep surface of the parotid gland higher up. The hypoglossal nerve, the occipital artery, and the posterior auricular artery also cross it beneath the sterno-mastoid. Passing obliquely across its anterior and outer surface and separating it from the external carotid are the stylo-pharyngeus, the tip of the styloid process, the stylo-glossus muscle, the glosso-pharyngeal nerve, and the pharyngeal branch of the vagus.

Internal to it is the external carotid below, and above that are the wall of the pharynx, the ascending pharyngeal artery, the pharyngeal plexus of veins, and the external and internal laryngeal nerves; near

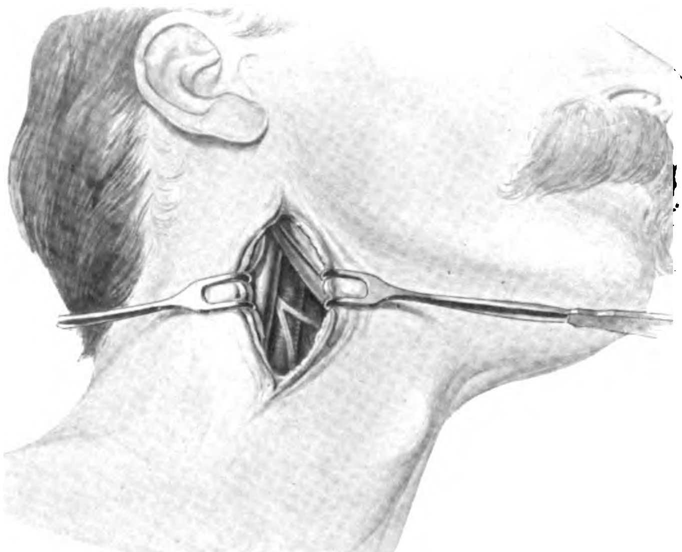


FIG. 214. LIGATURE OF THE INTERNAL CAROTID ARTERY. The internal jugular vein is seen behind the artery, while crossing it is the hypoglossal nerve, giving off its descending branch.

the entry of the vessel into the carotid canal are the levator palati muscle and the Eustachian tube. Somewhat to its *outer side,* and rather posterior, are the internal jugular vein and the vagus nerve.

Operation. The positions of the patient and the surgeon are the same as in the last operation. An incision about three inches long is made along the line of the artery (see p. 507), corresponding closely to the anterior border of the sterno-mastoid and commencing just below the upper border of the thyreoid cartilage (see Fig. 211). The anterior margin of the sterno-mastoid is pulled well back, and the bifurcation of the common carotid is exposed. It should be remembered that the internal carotid is superficial and posterior to the external at this point. Another means of identification is the absence of branches from the internal trunk, and the presence of the internal jugular vein on its outer side (see Fig. 214). The needle is passed from without inwards.

LIGATURE OF THE VERTEBRAL ARTERY

Indications. These must always be extremely rare; indeed, the operation is practically a mere dissecting-room exercise. In the living subject it might be required for stabs or traumatic aneurysm of the vertebral. Some years ago it was much advocated for the cure of epilepsy, but time has shown that it does not exert any real restraining influence on the disease. Owing to the depth at which the artery is situated, and the importance of the structures by which it is surrounded, the operation must always be one of great difficulty. Should it be necessary to expose the vessel for injury or traumatic aneurysm, this difficulty will be increased enormously.

Surgical anatomy. The vertebral artery is the first branch of the subclavian, and springs from its upper and back part just opposite the septum between the scalenus anticus (anterior) and the longus colli muscles. It runs up in the interval between these two muscles and ends at the lower border of the pons, where it unites with its fellow on the opposite side to form the basilar artery.

Relations in the neck. The artery lies in the interval between the inner border of the scalenus anticus (anterior) and the outer border of the longus colli. It is crossed by the internal jugular and the vertebral veins, by the inferior thyreoid artery, and, on the left side, by the terminal portion of the thoracic duct. It is surrounded by a plexus of sympathetic nerve fibres, and enters the foramen in the transverse process of the sixth cervical vertebra.

Operation. The positions of the patient and the operator are the same as for ligature of the common carotid (see p. 507), except that the head is turned rather more forcibly to the opposite side. An incision three and a half inches long is made along the posterior border of the sterno-mastoid, extending downwards as far as the clavicle. Before the deep fascia is reached, the external jugular vein should be identified, as it runs almost parallel with the margin of the muscle, and must be avoided if possible; if not, it must be divided between two ligatures before it pierces the deep fascia. The deep fascia has now to be divided along the posterior edge of the sterno-mastoid, and that muscle and the jugular vein are drawn inwards, the head being bent to allow this to be done; should the patient be stout, or the muscle unduly large, it may be partially divided from the clavicle, if necessary. The artery lies very deep, and the best guide to it is the outer edge of the scalenus anticus (anterior), which lies parallel to and deeper than the outer border of the sterno-mastoid. When this muscle has been identified, the interval between it and the longus colli is looked for. Help may be obtained by feeling the transverse process of the sixth cervical vertebra

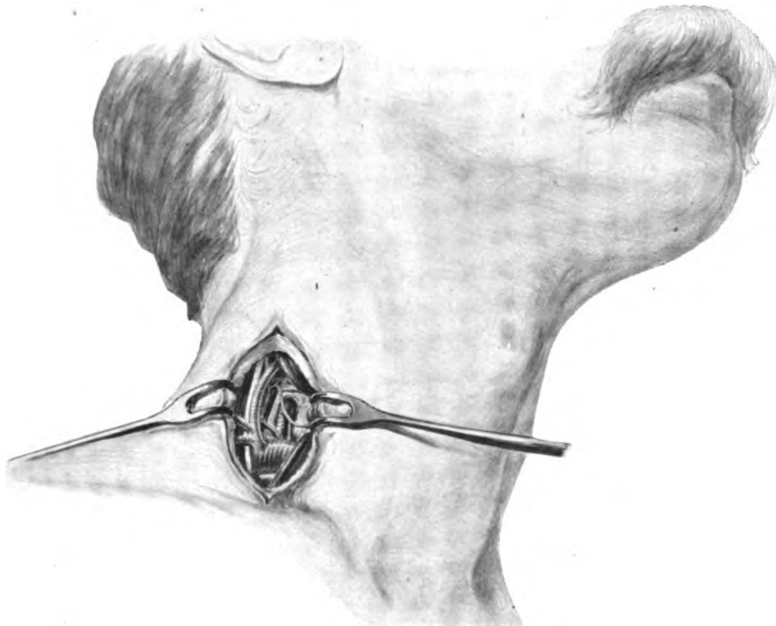


FIG. 215. LIGATURE OF THE VERTEBRAL ARTERY. The sterno-mastoid is pulled forwards and the artery is seen entering the foramen in the transverse process of the sixth cervical vertebra. It is difficult to convey an idea of the great depth at which the vessel lies.

in the wound; the artery can generally be felt deep down beneath it (see Fig. 215).

The operation is exceedingly difficult owing to the depth at which the artery is placed and to the free venous oozing. The vertebral and internal jugular veins lying directly over the artery are a great source of hindrance to the operator, and it is easy to wound the former, which, however, may be tied without hesitation. The muscles of the neck must be relaxed as far as possible, the wound widely retracted, and a powerful illumination secured. The needle should be passed from without inwards. It is said that the fibres of the sympathetic are always interfered with in ligature of this vessel, and contraction of the corresponding pupil is usually met with when the ligature has been applied successfully.

LIGATURE OF THE LINGUAL ARTERY

Indications. (i) The artery is usually tied either *in the course of, or as a preliminary to, excision of the tongue.* In the former case the artery will be secured at or near its origin from the external carotid, and that operation will not be described here as it merely entails exposure of the artery in the wound made for the removal of the submaxillary lymphatic glands, which is a part of the operation for removal of the tongue. When the vessel is found, it is traced back to its origin and a ligature is applied to it. When, however, ligature is performed as a preliminary to removal of the tongue, the vessel is usually tied in what is called its second part, viz. the portion lying beneath the hyo-glossus muscle.

(ii) Both lingual arteries are not infrequently tied in order *to restrain hæmorrhage* from a cancerous growth of the tongue, or to starve the growth by cutting off its blood-supply. In this case it is well to tie the artery in its first part, namely, near its origin from the external carotid, as thereby all its branches are cut off.

(iii) Ligature may be required for *a wound of the vessel,* such as a stab. In this case the wound should be enlarged and the bleeding points sought for and tied.

Ligature of the artery may be practised in two situations, viz. near its origin from the carotid—the so-called ' first part '—or as it lies beneath the fibres of the hyo-glossus, in the so-called ' second part '.

LIGATURE AT ITS ORIGIN

Ligature of the vessel in its first part is practically identical with ligature of the external carotid (see p. 514), save that the ligature is applied to the lingual branch instead of to the external carotid trunk; it need not be described here.

LIGATURE BENEATH THE HYO-GLOSSUS MUSCLE

Surgical anatomy. The second part of the lingual artery passes beneath the hyo-glossus muscle, which separates it from the hypoglossal nerve, the lingual vein, and a portion of the submaxillary gland. It lies upon the middle constrictor of the pharynx, and its course beneath the hyo-glossus is usually indicated by the hypoglossal nerve, which lies superficial to that muscle. From this part of the artery the dorsalis linguæ branch arises and supplies the back part of the tongue. In order to make sure that this branch is controlled, therefore, the ligature must be applied quite far back, practically at the junction of the first with the second part.

Operation. The head and shoulders are somewhat raised, and the chin is turned well to the opposite side, drawn upwards, and steadied by an assistant. The surgeon stands upon the same side and makes an incision through the skin and deep fascia, commencing just below

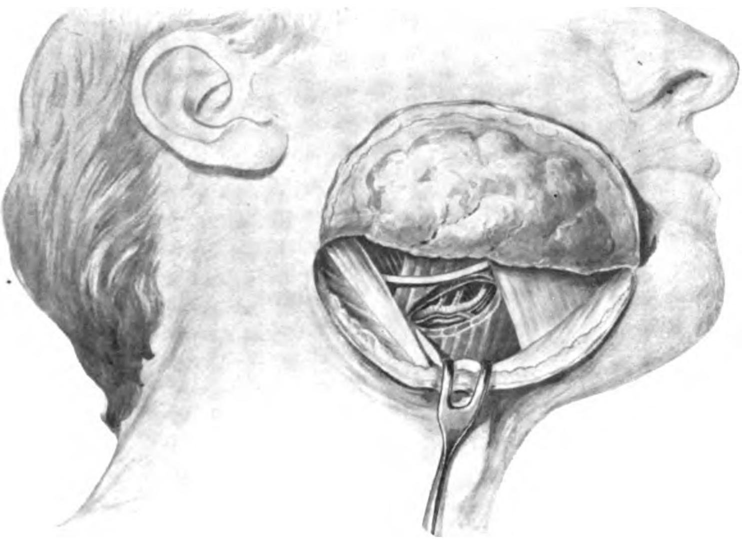


FIG. 216. LIGATURE OF THE LINGUAL ARTERY. The artery is seen through the incision in the fibres of the hyo-glossus. The hypoglossal nerve has been displaced slightly upwards.

and outside the symphysis menti, and running downwards to the hyoid bone, whence it curves upwards and backwards nearly to the angle of the jaw (see Fig. 211); in doing this, free oozing may occur from branches of the facial and anterior jugular veins which will need to be controlled. The deep fascia is divided by a horizontal incision parallel to and almost over the hyoid bone, which exposes the submaxillary salivary gland; this reaches almost down to the hyoid in the living subject, and completely so in the dead. The gland is now raised from its bed partly with the handle of the knife, and partly by a few touches of its point; the gland structure itself must not be damaged, and the skin and gland should be raised together and fastened to the cheek with a fine suture so as to avoid having to retract it forcibly in the later stages of the operation.

The digastric tendon, with the two bellies of the muscle, and the mylo-hyoid will now be seen in the front part of the wound. The fascia is cleaned from the posterior margin of the mylo-hyoid, and the digastric tendon is defined and pulled firmly downwards and backwards with a blunt hook, so as to bring into view the fibres of the hyo-glossus muscle, which run almost vertically. The hyo-glossus is crossed horizontally by the prominent hypoglossal nerve, which runs parallel to and almost over the artery, the hyo-glossus fibres, however, being interposed between the two. Below the nerve, and also superficial to the hyo-glossus, lies the lingual vein. These two structures are gently displaced upwards with a blunt hook, and the fibres of the hyo-glossus are cut through with the point of the knife immediately above and parallel to the margin of the hyoid bone. This incision is made with great care, and to a slight extent only at each stroke of the knife. The cut muscular fibres retract immediately, so that the artery is soon seen protruding through the cut (see Fig. 216); it is usually somewhat tortuous, which renders it more prominent when exposed. The needle is passed round it in whichever way seems easiest. The submaxillary gland and the skin flap are then laid down in place and sutured. If all bleeding points be secured by ligature there is no need to employ a drainage tube.

Difficulties and dangers. This operation is by no means as easy as a perusal of its steps might lead one to suppose. Amongst the chief difficulties may be enumerated:—

(i) *Too short an incision.* This is only likely to occur when the operation is not a part of a complete removal of the tongue and the submaxillary lymphatic glands. The surgeon, in order to minimize the scar made by the operation, is tempted to shorten his incision by curving it upwards from the hyoid bone to the point at which the facial artery crosses the ramus of the lower jaw. It is quite possible to secure the vessel through this incision, and the short incision is often used, but it limits the access to the vessel, and good retraction and much accuracy of operating is required to enable the operator to secure the vessel satisfactorily.

(ii) *Difficulty with the submaxillary gland.* This structure extends lower down than might be thought, and, in raising it, the tendency is to cut through the gland instead of getting properly below it and lifting it out of its bed undamaged. Unless due care be exercised, not only may serious damage be done to the gland itself, but the surgeon will be much hampered in defining the structures met with, and there will be troublesome oozing which it is difficult to stop.

(iii) *Difficulty in finding the artery after incising the hyo-glossus.* The chief danger here is that the cavity of the pharynx, from which the artery is only separated by the middle constrictor and the mucous membrane, may be opened at the first cut of the knife. There should be little difficulty in finding the artery if the fibres of the hyo-glossus be cut through little by little and separated as they are cut, and if the incision be made strictly parallel to and less than a quarter of an inch above the body of the hyoid bone.

(iv) *Wound of the pharynx in passing the needle.* This is a serious matter owing to the risk of secondary hæmorrhage from sepsis. It is, however, easily avoided. When found, as described above, the artery

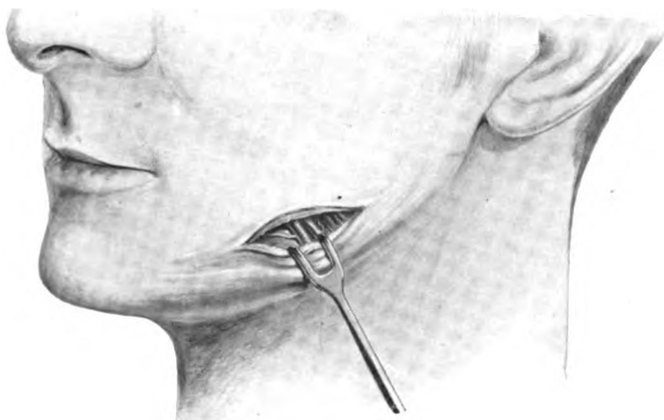


FIG. 217. LIGATURE OF THE FACIAL ARTERY. The vein is behind the artery.

should be seized in forceps, when it can be stripped off the middle constrictor and traced back to the edge of the hyo-glossus, or at any rate to the proximal side of the origin of the dorsalis linguæ branch, where the ligature should be applied.

LIGATURE OF THE FACIAL ARTERY

This operation and the three following ones are mere dissecting-room operations and do not require extended notice.

Ligature of the facial artery is hardly ever done as a formal operation. When the artery is tied it is usually in the course of some other procedure, such as the excision of the lower jaw.

It may be secured at its commencement, as already described under ligature of the external carotid artery (see p. 514), or at the point where it crosses the lower jaw—as for a wound of the face. This point corresponds to the anterior margin of the masseter, and the only thing worthy of note is that the incision should be parallel with the lower border of the jaw, so as to avoid damage to the facial nerve. The facial artery is easily recognized by its pulsation as the wound is deepened. The facial vein lies behind the artery (see Fig. 217), and the needle should therefore be passed from behind forwards.

LIGATURE OF THE TEMPORAL ARTERY

This may be required for a wound of the scalp, the bleeding from which cannot be controlled otherwise.

The vessel is secured through a vertical incision about half an inch

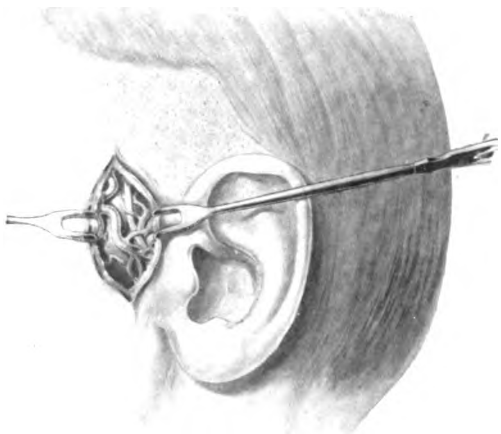


FIG. 218. LIGATURE OF THE TEMPORAL ARTERY. The auriculo-temporal nerve lies behind the artery.

in length midway between the tragus and the condyle of the jaw. There is no difficulty in the living subject, as this is one of the situations in which the pulse is usually felt. The artery is tied as it crosses the root of the zygoma, and here it is only covered by skin and fascia. The vein lies behind the artery, which is crossed by branches of the temporo-facial vein and the facial nerve (see Fig. 218). The needle should be passed from behind forwards.

LIGATURE OF THE OCCIPITAL ARTERY

This may be required for conditions similar to those requiring ligature of the temporal artery; it has been done for an occipital aneurysm. The vessel may also be tied to complete the operation for ligature of the external carotid (see p. 514). In this case the operation is similar to that for ligature of that vessel and needs no description here.

Ligature of the terminal portion of the artery. This is done through an incision about two and a half inches long, extending from the tip of the mastoid process in the direction of the external occipital protuberance. The artery, lying in the occipital groove, emerges from beneath the posterior belly of the digastric, having on its inner side the rectus capitis lateralis, which separates it from the vertebral artery. It is here under cover of the sterno-mastoid, the splenius capitis, and the trachelo-mastoid (longissimus capitis) muscles. At its termination the great occipital nerve crosses it, and the vessel either pierces the aponeurosis

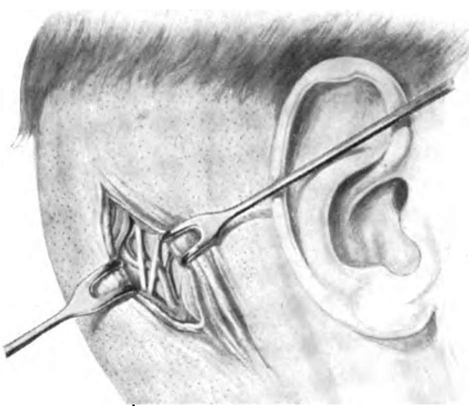


FIG. 219. LIGATURE OF THE OCCIPITAL ARTERY. The great occipital nerve crosses the vessel. The ligature is applied at the extreme lower end of the wound, where the vessel emerges from beneath the mastoid process.

uniting the sterno-mastoid and the trapezius to pass through the deep fascia, or it perforates the posterior part of the occipito-frontalis (epicranius) muscle.

The incision is deepened until the sterno-mastoid is exposed, and the fibres of this muscle are divided throughout the length of the incision, and those of the splenius identified. These are cut in their turn, with as much of the trachelo-mastoid (longissimus capitis) as comes into the wound. After the cut muscles have been retracted, the posterior belly of the digastric muscle comes into view, and the occipital artery will be seen emerging (see Fig. 219). In this situation the vessel lies upon the superior oblique and the complexus, and is about midway between the transverse process of the atlas and the mastoid process. The needle may be passed in whichever direction seems easiest.

This operation is often somewhat difficult owing to the abnormalities in the distribution of the artery. It is common to find a considerable part of the vessel superficial to the trapezius, and it is apt to be wounded in deepening the skin incision. The wound in which the vessel is usually secured is somewhat deep, and good light and careful sponging are essential; the application of adrenalin is useful in ensuring a good view.

CHAPTER XIII

OPERATIONS UPON VEINS

PLASTIC OPERATIONS

OPERATIONS for the repair of wounds in veins are rarely required. It is seldom worth while to go to the trouble of repairing a wounded vein so as to preserve the circulation through it; in an aseptic wound the obliteration of all but the largest veins, such as the axillary or the common femoral, is not likely of itself to give rise to more than temporary inconvenience and transient œdema; even in these the effects of ligature are not grave. In the majority of cases of wounds of veins, therefore, there is no objection to adopting the simpler and more rapid method of ligature of the vein above and below the wound.

Indications. There are certain cases, however, in which it is certainly advisable to close a wound in a vein without arresting the circulation through it permanently. A not infrequent accident in the course of operations upon the cervical glands is an injury to the internal jugular vein, and, although it is not a serious matter to apply a ligature above and below the wound in the vein and so occlude the vessel entirely, yet it is preferable to stop the bleeding by some means that will at the same time preserve the circulation through the vein, if this can be done without undue prolongation of the operation.

There are other cases again in which the repair of a wounded vein is most important. It happens occasionally that the renal vein is torn away from the vena cava during nephrectomy. This results in furious hæmorrhage which it is difficult to stop and which it is out of the question to arrest by applying a ligature to the vena cava above and below the entrance of the renal vein. Occasionally also in pelvic operations one of the iliac veins has been wounded, and in this situation also an operation that will close the wound, and at the same time allow the circulation through the vein to remain unimpaired, is of great value.

Operation. (i) For small wounds, such as *punctures*, or for *avulsion of a tributary* close to the main trunk, it is sufficient to pick up the bleeding point in the wall of the vein and surround the opening in it with a lateral ligature. The low blood-pressure in the vein is not likely to cause dislodgement of the ligature, provided that this be tied very tight. It not infrequently happens that, during operations upon glands in the neck, when a lateral ligature of this kind has been placed upon the internal jugular there is a recurrence of hæmorrhage; this is generally due to an insufficiently firm ligature.

(ii) When there is a *longitudinal or transverse slit of any considerable extent,* and more particularly when a portion is sliced out of the vein, this method will not do, and the wound in the vein must be sutured. As a matter of practice it is found that almost any method of suture will do, and the one commonly employed has been a continuous running suture taking up all the coats of the vessel. The circulation is arrested on each side of the wound by digital or instrumental pressure, and the edges of the incision in the vein being held together with very fine toothed forceps, they are sewn up by the finest spring-eyed, fully curved, round intestinal needle carrying the finest obtainable catgut. The suture should begin about one-eighth of an inch beyond one end of the wound and should extend for about the same distance on the far side; a single row of sutures is sufficient. A suture identical with Dorrance's for arteriorrhaphy (see p. 379) may be used, and is perhaps less likely to be followed by thrombosis, as the suture does not then project into the blood-stream.

ARTERIO-VENOUS ANASTOMOSIS

This has already been described fully in connexion with the operations for reversal of the circulation of a limb. It has also been suggested—although, as far as I am aware, not carried out in practice—that the cure of a fusiform aneurysm might be effected by dividing the parent vessel above and below the sac and performing an end-to-end anastomosis, using as an intermediary in the gap caused by the removal of the aneurysmal sac a suitable portion of the companion vein. That this is ever likely to become a recognized operation is very doubtful, and that it is preferable to simple ligature of the artery above and below the sac is open to question. To employ the main vein for the purpose of anastomosis is very likely to result in gangrene, owing to simultaneous blocking of the artery and the vein, whereas the older operation would obliterate the artery alone, leaving the circulation in the vein unimpaired. It has yet to be shown moreover that an anastomosis of this kind, where the rough cut ends of the artery, as well as the sutures, are exposed in the blood-stream, can successfully resist the tendency to thrombosis which is well known to exist under these circumstances.

OPERATIONS UPON VARICOSE VEINS

In this connexion the operations upon varicose veins of the extremities alone will be considered. Those upon the veins of the pampiniform plexus will be considered in the section devoted to operations for the cure of varicocele; while those upon the veins of the hæmorrhoidal plexus are the operations for piles and are dealt with among operations upon the rectum.

Methods. Properly speaking there is only one operative treatment for the cure of varicose veins, namely, excision between ligatures, but the two methods by which this is done differ both in technique and in results; they are:—

(*a*) *Trendelenburg's operation,* or division of the internal (great) saphenous vein between ligatures applied a little below the saphenous opening.

(*b*) *Excision of the varices* wholly or in part, with or without removal of the internal (great) saphenous trunk.

Indications. The following facts bearing upon the operative treatment of varicose veins are gradually becoming recognized:—

(*a*) That excision of varices is not a radical cure of the affection; the benefit is only temporary, other veins enlarging in due course.

(*b*) That pronounced varices on the inner side of the leg and knee are most prone to complications, such as thrombosis, &c., presumably from their position, which exposes them to injury or irritation.

(*c*) That the most important factor bearing on the well-being of the subjects of extensive varicose veins is the competency or otherwise of the valves in the saphenous vein. As long as these are doing their work efficiently there is only slight discomfort and possibly the risk of traumatic complications, but when they cease to act satisfactorily, sensory and circulatory troubles are prone to set in.

A consideration of the above facts leads to the conclusion that the following groups of cases are most suitable for operation:—

(i) Those in which there is insufficiency of the valves, as shown by the test introduced by Trendelenburg. To do this, the limb is emptied of blood by elevation, and pressure is made upon the saphenous opening until the patient resumes the upright position. If then the vein fills rapidly immediately the pressure on the saphenous vein is removed, it may be taken for granted that the valves are insufficient to hold up the column of blood in the vein.

(ii) Chronic ulcers of the leg in subjects of varicose veins. Here the operation is done with the object of removing the constant congestion and thereby facilitating rapid healing.

(iii) Serious hæmorrhage either from a vein that has burst or from one in the wall of a chronic ulcer that has ulcerated through.

(iv) Localized varices limited to one area of the limb but unaccompanied by swelling of the foot or marked pain. Here the operation is generally done to enable the patient to enter one of the public services.

(v) Prominent varices in a region, such as the inner side of the knee, preventing the patient from following some particular calling or exercise, such as riding, &c., in which the varices would be exposed to injurious pressure.

In all but the two last groups of cases, which however are large, the operation of choice will be that known as Trendelenburg's, or division of the internal (great) saphenous vein below the saphenous opening, whilst in the last two groups the chief object of the operation will be to remove the actual varices, and this may or may not be combined with Trendelenburg's operation. Personally, I always do Trendelenburg's operation at the same time as I remove those varices which are exposed to pressure or injury about the inner side of the knee and upper part of the leg.

Operations. Trendelenburg's operation is extremely simple and only occupies a short time, whereas the operation for the removal of the individual varices is often extremely difficult and tedious, not infrequently lasting two hours or more. In cases such as these it is well to remember that the operation can be done satisfactorily under the infiltration method of local analgesia (see p. 114).

Preliminary purification. In all these cases there are two points of great importance to be remembered. The first is that the most scrupulous care must be bestowed upon the aseptic precautions, as suppuration in the neighbourhood of these large veins would be a disaster of the first magnitude, and it is very easy to go wrong in this matter owing to the length of time consumed in the operation, and the various manipulations of the limb that are often required to get at the field of operation properly. The entire limb should always be shaved from the groin to the foot and thoroughly purified back and front. The foot should be wrapped up in a sterilized towel and by it all the movements of the limb should be made. The surgeon should confine himself as much as possible to the use of scalpel and forceps, and should handle the wounds as little as possible.

Mode of identifying the veins. The second point is to remember that it may be most difficult to identify the affected veins on the operating table, especially when excising local varices, unless some special means have been taken to facilitate this. There are several ways of doing this. The patient is made to stand up after the limb has been purified and before the overnight compress is put on, and, as soon as the veins have become fully prominent, they are marked out either with an aniline pencil dipped in a sterile solution, or by a solution of nitrate of silver (60 gr. to the oz.) painted on with a fine camel's-hair brush and allowed to dry; in the course of twelve hours this causes an indelible brown stain upon the skin. If the stain has not appeared at the time of the operation next morning it may be developed by brushing over the surface with a solution of pyrogallic acid. This nitrate of silver method is an excellent one, and leaves a stain that no purification on the operating table will eradicate. The aniline pencil-mark, on the other hand, although it is indelible as far as the overnight compress is concerned, gets washed out during the process of purification on the operating table, and in order to avoid this when aniline markings have been used I always mark in the proposed incisions lightly with a touch of the knife before the final purification is begun; the bleeding scratches thus made cannot be overlooked when the purification has been completed.

Trendelenburg's operation. An incision about three inches long is made over the line of the internal (great) saphenous vein, which can always be felt or seen before the operation sufficiently well for it to be marked out. The vein is exposed and dissected free from nerve filaments and surrounding fat, and a ligature is applied to it about two inches below the saphenous opening. A second ligature is applied two or three inches lower down and the intervening portion of the vein is removed; the wound is sewn up without a drainage tube. Fine chromicized catgut is the best material for ligature.

Excision of varices. As far as possible the incisions should be planned to take in venous junctions so that each incision may remove portions of more than one vein. There is no necessity to make long incisions except when it is desired to reach several junctions from one incision or when only a single group of veins, such as the internal (great) saphenous and its tributaries, is affected, in which case a long incision will block the venous return from a large area. Even here, however, incisions about two inches long are sufficient, and with them there is less danger of damaging the sensory nerve-supply; as a rule they should be made directly over the vein that is to be removed. Occasionally, however, it will be better to turn back a flap and remove a mass of veins from beneath it; this is advisable in the case of varices and their tributaries which are collected into large whorls or bundles. This method, however, is not advisable if it can be avoided, as the varices frequently thin the skin over them so much that the nutrition of the flap may be interfered with in raising it.

The skin incision should be deepened with care, as it is important to avoid wounding the veins if the surgeon wishes to do the operation as expeditiously as possible. In order to render the field of operation bloodless he may, if he chooses, use an Esmarch tourniquet, but this should be avoided, except when it is absolutely necessary, on account of the oozing that follows its removal and the possibility of thrombosis of the veins at its point of application. Blood collecting in these wounds is likely to give trouble subsequently, and therefore the use of the tourniquet should be restricted to the rarer cases in which it is essential to raise a flap and remove a mass of tortuous veins occupying a large area, and from which the bleeding would otherwise be very profuse before the main branches could be secured.

The enlarged veins are connected to the skin by a series of fine fibrous bands, which require division with the point of a very sharp knife. The least possible handling of the skin should be practised; very fine toothed forceps are best for this purpose. As soon as the skin has been separated from the vein, the remainder of the operation is easy, a few strokes with a blunt dissector or the point of the knife sufficing to isolate the vein and its tributaries from the surrounding fat. No attempt, however, should be made to effect this separation with any blunt instrument until the skin and its fibrous processes have been properly dissected off the vessel. The upper end of the main vein should be isolated first, picked up and clamped close up to the upper end of the skin incision in two pairs of forceps and divided between them. The portion of the vein to be removed is then raised by taking hold of the lower pair of forceps and putting the vein on the stretch; this renders all its tributaries apparent, and enables them to be dissected cleanly from the surrounding structures and clamped and divided in turn so that the whole portion of the vein is dissected downwards and removed; it is important to effect the separation of the veins from the surrounding structures cleanly, as otherwise cutaneous nerves may be tied in with the vein and the patient may suffer considerably.

When all the branches have been clamped and divided, the lower end is clamped and the entire mass is removed. Fine chromicized catgut ligatures are now applied to the clamped ends, and it is a point of some practical importance to see that the knot of the ligature is turned towards the deep surface of the wound, so that there is no risk of the cut ends of the ligature projecting from the skin wound when the latter is sewn up. Owing to the thinness of the skin and the proximity of the veins to it, this troublesome little accident is very likely to occur unless special pains be taken to avoid it. Another small point of practical importance is to dissect the skin up for a short distance above and below the ligatured ends of the veins, so that the catgut lies well hidden beneath the skin. If the ligature projects from the wound it always comes away later on and will thus prolong convalescence. If the steps described above are carefully followed, the operation can be done almost bloodlessly.

It is well not to sew up the wound at the time it is made, but to cover it with a piece of sterilized gauze and to proceed to remove all the rest of the veins that it is desired to excise before sewing up any of the wounds. This enables one to see whether there are any other bleeding points that require ligature, and ensures a perfectly dry wound at the end of the operation, when all the incisions are sewn up *seriatim* in the order in which they were made. No drainage tube is required, but it is most essential to see that the wound is dry before it is sutured. It is well to use fine silkworm-gut, horsehair, or Michel's sutures, as they are all non-absorbent, and even slight staphylococcic infection from the skin may lead to serious consequences.

Occasionally it may be necessary to excise a large mass of veins that have so thinned the skin over it as to endanger its vitality when raised as a flap, and in these cases it may be necessary to plan the skin incision so that a certain portion of the skin may be excised and the wound brought together afterwards. Under such circumstances it is well to employ a tourniquet, as the veins are certain to be wounded during the operation, and otherwise there will be so much oozing, that it will be very difficult to see the condition of the parts, and a good deal of unnecessary damage may be caused. After the dressings have been applied, the knee should be kept steady between sand-bags and more or less fixed; it is not necessary to employ a splint unless the patient is restless.

After-treatment. The stitches should be removed about the eighth day and a collodion dressing applied. The patient should be kept in bed for a fortnight and should spend the following week on a couch; at the end of that time he may walk about.

VENESECTION

Indications. For any condition accompanied by engorgement of the right side of the heart. The operation is rarely practised at the present day, but it has a definite sphere of usefulness, and in many cases is of the highest value. In diseases like chronic bronchitis accompanied by over-distension of the right side of the heart and intense engorgement of the systemic venous system, venesection may act like a charm by mechanically removing this undue pressure, and may thus enable the patient to tide over the critical stage of his illness.

Operation. Slight as it is, this operation must be done skilfully in order to ensure a satisfactory result. As a rule no general anæsthetic is permissible, and it is not even necessary to use any local analgesia (see p. 114); but there is no objection to the use of local infiltration should the surgeon desire it, although it must be remembered that the proper performance of the operation depends very largely upon the accurate definition of the vein, and that any subcutaneous œdema will obscure the parts. The patient should be in the semi-recumbent position so that he may be readily laid flat should he be faint. In no case should venesection be performed with the patient in the upright position.

In order to render the veins prominent a single loop of bandage or broad tape is fastened moderately tightly around the middle of the upper arm in order to compress and distend the cutaneous veins. In order to effect this object still better the patient is made to clench his hand firmly or to grasp some moderate-sized object firmly in it. This renders prominent all veins in the forearm. The vein selected is usually the median basilic, because of its large size and superficial position. Venesection is hardly ever done in any other situation except at the bend of the elbow; in former days it was frequently practised at the ankle and on the temporal and external jugular veins.

The region of the median basilic is thoroughly purified in the ordinary manner, and the surgeon places his left thumb immediately below the spot at which he is going to incise the vein. This is done with two objects, viz. to steady the vein during the incision, and to enable the thumb to be slipped over the incision immediately it is made, and thus to check the outflow of blood until the lancet is put down and the bleeding-bowl is in position. The incision is made with a fine double-edged lancet, grasped between the thumb and forefinger close to its point and steadied by resting the right hand upon the left thumb. This is a necessary precaution, as the incision into the vein must be judged to a nicety, otherwise it is quite easy to make the incision either too superficial, in which case the vein is not opened, or too deep, in which case both walls of the vein may be transfixed, the bicipital fascia beneath divided, and the brachial artery itself wounded; this was a common accident in former days and was the cause of the arterio-venous aneurysms that were so frequently met with in this region.

The incision should open the vein at the first attempt and should divide its anterior wall parallel with its long axis and in the middle of its anterior aspect. The left thumb is at once placed over the opening, the lancet is put down, and the vessel into which the blood is to be received placed beneath the limb; the limb is then turned over so that the opening in the vein is downwards and the pressure taken off the incision. After the requisite amount of blood, which varies from six to twelve ounces, has been removed, a small gauze pad is firmly fastened over the opening in the vein, the bandage round the arm is removed, and the patient instructed to carry his arm in a sling for a few days until the wound has healed. The bandage round the arm should be fastened by a slip-knot so that it can be easily pulled off with one hand, and the gauze pad over the incision may be fastened in position by a piece of broad tape passing around the elbow-joint in a figure-of-eight.

INTRAVENOUS INFUSION

Physiological salt solution may be of value temporarily, but a wide experience in cases of secondary hæmorrhage during the recent war showed that salt solution injected intravenously passed rather rapidly into the capillaries and body tissues, and that the rise of blood pressure resulting from its administration was only temporary.

Intravenous infusion should never be used for the relief of severe hæmorrhage unless the source of bleeding has been secured. In severe hæmorrhage the blood pressure falls so low that at last spontaneous arrest of the bleeding occurs, and to raise the blood pressure without securing the bleeding point merely causes the bleeding to commence afresh. If it is impossible to secure the bleeding points it is better to trust to the chance of thrombosis by natural processes rather than run the risk of raising the blood pressure by infusion and causing the hæmorrhage to recur.

In cases where large amounts of fluid have been lost by repeated and persistent vomiting as in the toxæmias of pregnancy, in acidosis, acute gastric dilatation, and postoperative vomiting, if proctoclysis is unsuccessful, intravenous infusion will help to restore the body fluids. In most cases, however, the subcutaneous administration of salt solution is to be preferred because of the simplicity of administration, because it may be continued without difficulty over a considerable period of time, and because there is less likelihood of embarrassing the circulatory mechanism by suddenly throwing a large quantity of fluid into the circulation.

Operation. The vein usually chosen is the median basilic. By light circular constriction upon the arm the vein may be made to become filled with blood, and prominent. The sharp beveled needle can then be thrust into the vein without incision of the skin. If this is impossible, the vein may be dissected out under local anæsthesia. It is exposed by a cut directly over it, and is rapidly separated from the surrounding tissues with a blunt dissector for a distance of three-quarters of an inch or more. An aneurysm needle carrying a double ligature of catgut is passed beneath the vein, and the two ligatures are separated, one being drawn to the lower end of the vein, the other to the upper. An incision is made in the anterior wall of the vein large enough to admit the nozzle of the fine cannula which is sold for the purpose. This is introduced with its nozzle pointing towards the heart, that the stream of fluid from it shall be in the same direction as the venous flow. The upper ligature is tied around the point of the cannula; the lower one is tied around the vein below the incision and its ends cut short. The sterilized normal saline solution at the body temperature, which may contain about a drachm of 1:1,000 adrenalin chloride, is now run into the vein. Care should be taken to see that there are no air-bubbles in the apparatus. The infusion should be made quite slowly, the receptacle being raised only slightly above the level of the heart. The amount introduced is regulated by the effect of the infusion upon the pulse. As a rule at least two pints may be injected before any marked alteration can be detected, but after this amount has been introduced the pulse becomes slower and improves in volume. As a rule about three pints are usually sufficient for cases of bad hæmorrhage or severe shock. When the infusion is being carried out for the relief of shock, it is a good plan to leave the cannula and apparatus in position, so that the infusion may be repeated if necessary. In cases of hæmorrhage, it is not as a rule necessary to repeat the infusion, so the cannula may be withdrawn and the upper end of the vein permanently ligated.

Difficulties. The chief difficulty in the operation is to identify the vein in the collapsed condition present in severe hæmorrhage or bad shock. It is often impossible to distend the veins sufficiently to identify them, and perhaps the best plan is to cut transversely across the direction of the median basilic and thus divide the vein completely. The two open ends can then be seen in the wound, the lower one tied, and the point of the cannula introduced into the upper one and secured there.

CHAPTER XIV

SURGERY OF THE LYMPHATICS

By W. Sampson Handley, M.D., M.S., F.R.C.S.
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Injuries of lymphatic vessels. The anastomoses of the lymphatic system are so free that wounds of even large lymphatic trunks usually give rise to no trouble and pass unrecognized.

The thoracic duct itself has not infrequently been wounded during operations at the base of the neck upon the left side. The accident is followed by free escape of milky chylous fluid for some days, but the discharge gradually ceases and no evil consequences follow as a rule, though in some recorded cases the discharge of chyle has been persistent and ultimately fatal.

If the accident is recognized at the operation it may be possible to suture an incompletely divided duct. If the division is complete, ligatures should be applied to the cut ends. If they cannot be found, the wound should be closed and pressure applied. The accident has only once happened to me in a case in which I dissected out the glands on the left side of the neck for secondary deposits from left mammary cancer. Within two or three days a very profuse discharge of milky fluid escaped from the wound. The fluid appeared to be irritating, for the edges of the wound became swollen and congested, though there was no evidence of sepsis. The accident was treated by the vigorous application of pressure with a Martin's bandage. The patient wasted considerably, and her condition for several weeks gave rise to anxiety, but under the care of Dr. Distin, of Enfield, the discharge gradually lessened, and in about six weeks the wound was quite healed.

Lymphangitis, or inflammation of the lymphatic vessels, may be acute or chonic.

Acute lymphangitis occurs when, owing to the presence of a septic focus, pyogenic bacteria gain access to the lymphatic vessels and inflame them. It may occur in the absence of any recognizable focus of infection, within twenty-four hours of a puncture or abrasion of the skin so minute that it fails to attract the notice of the patient. The more prompt the appearance of symptoms, and the less obvious the point of entry of the virus, the more severe, as a rule, is the case.

An initial rigor frequently occurs within 24 hours, the temperature rises to 103° or 104° F., and upon the affected limb red lines can be seen, mapping out the course of the trunk lymphatics. The corresponding lymphatic glands are swollen and tender. The limb feels tense and heavy, and soon becomes the seat of a diffuse throbbing and burning pain while œdema of the skin makes its appearance. Within a few days the affection may subside, or it may lead to cellulitis or to suppuration of the lymphatic glands, or in the worst cases to a general septicæmia or pyæmia. It is rare for suppuration to occur in the lymphatic vessels themselves.

The milder cases may be effectually treated in the acute stage by rest and elevation of the limb and the application of lead lotion. Bier's passive hyperæmia by constriction is often useful. If the primary focus can be found it should be freely incised and fomented. If any discharge is coming from it an immediate microscopic examination should be made without waiting for a culture. If streptococci are seen 20 or 25 ccm. of antistreptococcic serum should be given immediately, and if staphylococci are detected from 50 to 100 millions of a staphylococcus vaccine should be injected subcutaneously. If no means of microscopic examination are available both these measures should nevertheless be adopted as a precaution if the general condition of the patient is in any way serious, and more especially if delirium or other signs indicate a profound toxæmia.

As a local application in the severer cases glycerine or belladonna may be used, especially if pain is acute.

The preparation of an autogenous vaccine should be undertaken if the case does not yield to treatment by the time the results of the culture are known.

After an initial purge the general treatment must be of a supporting and sustaining character, and plenty of fluid nourishment should be administered in the shape of eggs, milk, and beef tea.

The treatment of cases which merge into glandular suppuration or pyæmia is hardly within the scope of this article. Cellulitis needs free multiple incisions into the subcutaneous tissues, followed by hot fomentations.

Tuberculous lymphangitis. This affection is of course a chronic one. As the result of the inoculation of tubercle bacilli upon a wound or abrasion, usually upon the hand, multiple subcutaneous thickenings appear along the course of the lymphatics of the affected limb. Here and there these indurations may break down into abscesses. At the same time the corresponding lymphatic glands become enlarged. In the case of the upper arm the bicipital gland is the first to undergo enlargement, and should especially be sought for. Diagnosis is complicated by the fact that the original tuberculous sore may be healed by the time the patient comes under observation. Before suppuration takes place the subcutaneous deposits closely simulate gummata, but their linear distribution, their restriction to one limb, and the marked glandular enlargement, usually permit a distinction to be made.

In the treatment Bier's congestion and tuberculin may be tried, but usually it will be necessary to incise and scrape out the local deposits, applying zinc chloride (twenty grains to the ounce) to the cavity left. The glands should not be incised unless they show signs of breaking down.

Lymphangiectasis is a condition comparable to varicosity of the veins, but affecting the lymphatic vessels. It may occur in any form of lymphatic obstruction. When the superficial lymphatics are affected, little colorless vesicles, from which lymph frequently oozes, may be present in large numbers upon the affected area of skin.

Elephantiasis Arabum is the name given to the extraordinary condition of hypertrophic lymphatic œdema of the skin and subcutaneous tissues which occurs in many hot countries. It is usually preceded by repeated attacks of acute lymphangitis in the affected limb, during which there are rigors, fever, and cutaneous erythema. The parts most commonly affected are a lower limb or the scrotum.

The skin is enormously thickened, the thickening affecting mainly the dermis. The papillæ may also be hypertrophied and papillomatous areas are frequently found upon the cutaneous surface. These are especially likely to occur between the toes. Owing to the impaired nutrition of the skin, ulceration is a frequent complication; the ulcers rapidly become septic and heal badly. The subcutaneous fatty tissue is more fibrotic than normal, and is immensely increased in thickness. Superficial to the deep fascia and in close contact with it, I have observed a very dense layer of œdematous fibrous tissue. This layer must necessarily strangle and obstruct the fascial lymphatic plexus which lies in this situation. This plexus receives tributaries, both from the skin above and from the muscles beneath. When it is obstructed, the lymph from the subcutaneous tissues has no alternative route for returning, but that from the muscles is able to flow back through the lymphatics which accompany the deep vessels. Accordingly, the changes in elephantiasis are mostly confined to the skin and subcutaneous tissues. The structures beneath the deep fascia are found upon examination to be practically intact except for a certain amount of muscular degeneration owing to disuse.

It will be seen later that these facts afford a useful suggestion for surgical treatment.

On Manson's authority it has been believed that elephantiasis is due to obstruction of the lymphatics by multitudes of filariæ, embryos of a worm which may be found in the lymphatics. The recent careful work of Dr. P. H. Bahr,[1] under the auspices of the London School of Tropical Medicine, has produced fresh evidence in support of Manson's hypothesis. Nevertheless this view may be only partially correct, for I have convinced myself that a condition indistinguishable from an extreme degree of elephantiasis may occur, though rarely, in patients who have spent their whole life in England, and who on repeated examination show no sign of filarial infection. These patients, like tropical ones, often give a history of recurrent lymphangitis. In one such patient, Mr. A. F. R. Foulerton and I found a chronic infection of the subcutaneous tissues by a micrococcus indistinguishable from the staphylococcus pyogenes albus. A French observer, Dufougeré, has repeatedly found micrococci present in the tissues in cases of tropical lymphangitis, and these organisms too are probably the white staphylococcus. It is thus highly probable, in my opinion, that tropical elephantiasis depends upon a chronic infection of the subcutaneous tissues by this organism, which is a normal inhabitant of the skin, although the filaria may be important as a carrier of the bacterial infection.

Treatment. The treatment of elephantiasis may be considered under the headings of (1) methods aiming at cure; (2) methods aiming merely at control; (3) methods of prevention.

1. In scrotal elephantiasis, amputation of the mass, which may be enormous, is a successful and, in skilled hands, a safe operation. In elephantiasis of the limbs, amputation is likely to be followed by recurrence of the disease in the stump. Flaying the whole limb down to the deep fascia, followed by skin grafting, has been practised in India, but I believe this plan to be dangerous and unsatisfactory in its results. Excision of the most prominent masses and folds is a useful operation. I have tried to treat the disease by burying silk threads in the subcutaneous tissues to act as lymphatic conduits (lymphangioplasty). In my own hands this plan has not been permanently successful and I am unable to recommend it. In fairness to my method I may add that several surgeons have recorded successes with it.

Various operative procedures have been introduced based upon the fact that there is an obstruction of communication between the superficial and deep lymphatics, due to the hypertrophy and fibrosis of the subcutaneous tissues. Rogers, Lanz, von Oppel, Rosenow, and Kondoleon devised operations to overcome this defect. To Rogers should be given the credit of first drawing the attention of the English-speaking world to the possibilities of this method of operative treatment. The

[1] P. H. Bahr, *Filariasis and Elephantiasis in Fiji* (London: Witherby & Co., 1912).

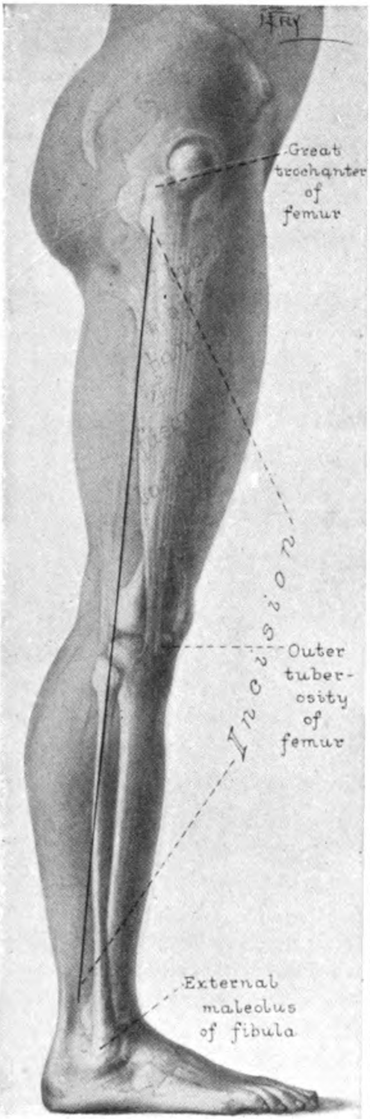

FIG. 220. ROGERS-KONDOLEON OPERATION. (*Sistrunk*)

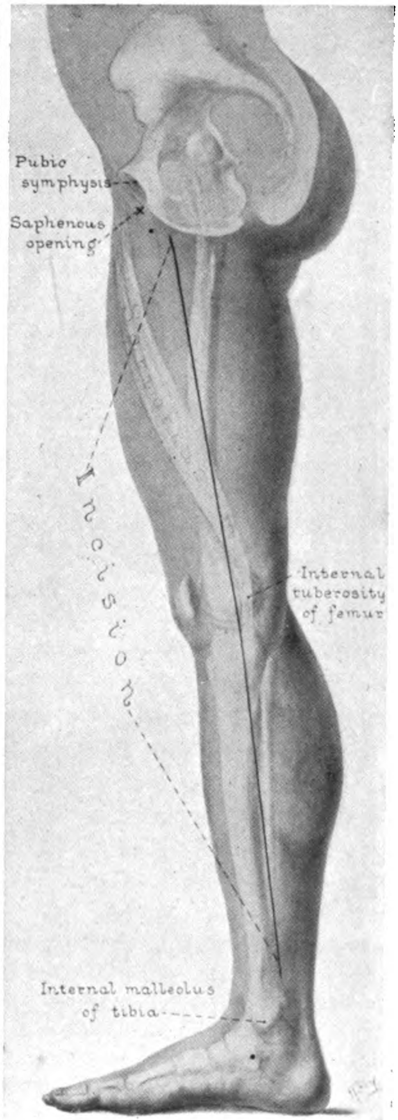

FIG. 221. ROGERS-KONDOLEON OPERATION. (*Sistrunk*)

procedure consists essentially in the removal of strips of the deep fascia and the excision of masses of the hypertrophic subcutaneous tissue. The deep fascia is exposed through long incisions at various parts of the limb, and multiple small portions of the fascial layer are excised over as large an area as possible. The incisions are then sutured. The operation aims at establishing a free communication between the lymphatics of the subcutaneous fat and those of the muscles. The lymph from the subcutaneous tissues thus finds its way back to the general circulation by way of the muscular lymphatic spaces and the deeper lymphatics in connection with them.

Theoretical objections to this operation are that it merely drains and does nothing directly to remove the hypertrophy, and that the aponeurosis removed may be replaced by scar tissue which would block the anastomotic channels. Apparently these objections do not hold because the affected members in time are reduced nearly to normal size and as far as has been observed the reduction is permanent.

Sistrunk advises that before operation the part should be elevated for four or five days, scrubbed daily with weak bichloride solution, and dressed with sterile gauze. The technique of the Kondoleon operation as he described it differs slightly from that detailed above. Long incisions are made along the inner and outer aspects of the affected limb and through each of these a large slice of œdematous fat is removed (Figs. 220, 221, 222, 223, and 224). The aponeurosis is then opened and a portion of it three or four fingers in width and the entire length of the skin incision is excised. The wounds are closed without drainage in such a way that the skin with the fat attached to it comes in contact with the exposed muscles.

In a case of elephantiasis of home origin I adopted operative treatment with very marked success, but in a similar more recent case the method failed.

The details of the first case are of sufficient interest to record here.

Lily, aged 15, attended my Out-patients' Clinic at the Middlesex Hospital in April, 1910, for swelling of the left thigh which began three months before. The swelling of the thigh had subsided to a certain extent, but there was much swelling below the knee. She was at first treated with a Martin's rubber bandage to the knee, and this greatly reduced the swelling of the leg while tending to increase that of the thigh. In October, 1910, vaccine treatment was begun with a dose of 250 millions of staphalbus vaccine, and this was repeated at weekly intervals without any apparent effect except a rather marked softening of the tissues, which was first noticed in June. At this time the calf measured 15¼ inches round and the thigh 24¾. In September, probably owing to the hot weather, the calf had increased to 16¼ and the thigh to 26 inches. The injections were continued at intervals throughout the next year, and in October, 1911, the calf measured 15 inches and the thigh 25½ inches. Massage was tried with the effect that the leg was temporarily softer after the treatment, but no permanent benefit was noticed.

In December the calf measured 17 inches and the thigh 23. The massage was therefore omitted, but the injections were continued with occasional intervals. On one occasion, when the interval was two months, the patient noticed increase of the swelling. She also volunteered the information that the injections made her tired and sleepy the next day, and for three or four days afterwards. These symptoms followed an injection of a thousand millions. Still, however, no further improvement took place, though the softening of the tissues was maintained. In February, 1913, the right thigh measured 24 inches

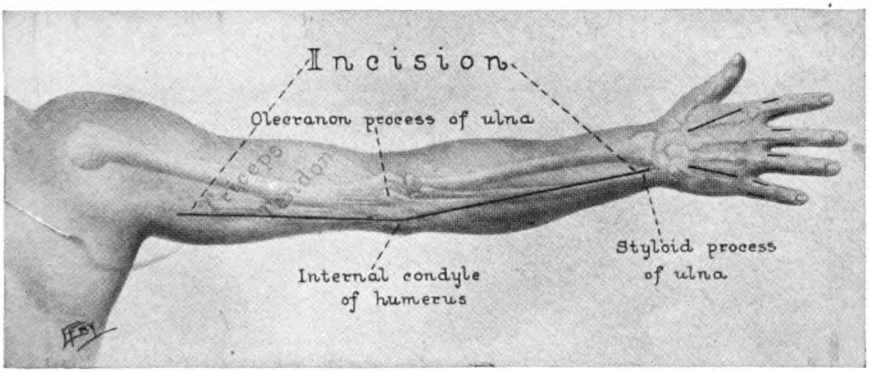

FIG. 222. ROGERS-KONDOLEON OPERATION. (*Sistrunk*)

and the calf 14. About this time I met with a description of the operation of fenestration of the deep fascia, and I performed it on the patient in the Putney Hospital about March, 1913. A reduction of the leg to 13½ and of the thigh to 22⅞ inches followed, together with marked softening of the tissues and increased comfort in walking. She was given an elastic stocking from the foot to the top of the thigh and in October, 1913, she reported herself as being in splendid condition. The left calf measured only one quarter of an inch more than the right, and the left thigh an inch more than the right. She became careless with the bandage and following its disuse some amount of swelling returned; on November 20th, the left calf measured 13⅝ inches, and the left thigh, six inches above the knee, 19½ inches. About Christmas, 1913, she contracted influenza and this time two blebs appeared on the skin and a certain amount of lymphorrhœa took place. Early in 1914 both thighs were the same dimension, the left one being as soft as its fellow, but the left calf measured 1½ inches more than the right. Thus, in spite of fluctuations from time to time, the result of fenestration in this case was a thoroughly satisfactory one. Sufficient time has now elapsed to make the prospect of a permanent cure very hopeful.

The vaccine treatment of elephantiasis will be considered later. Its scope is mainly preventive, but in some early cases it appears to be curative.

The constant use of a Martin's bandage, properly applied, will prevent any further marked increase of diameter in a limb which is already the seat of elephantiasis. This effect of pressure is illustrated in cases where boots have been worn. In such cases the foot and ankle are only slightly increased in size, as compared with the enormous overgrowth of the limb above the limits of pressure.

The patient should sleep with the foot of the bed raised. Massage may be useful, but it should be combined with vaccine treatment.

Method of prevention. I desire to draw the particular attention of medical men practising in the tropics to a promising field of thera-

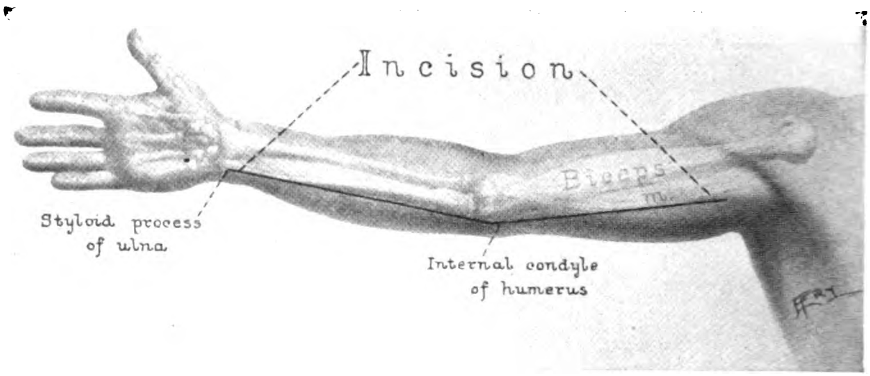

FIG. 223. ROGERS-KONDOLEON OPERATION. (*Sistrunk*)

peutic investigation—the prevention of elephantiasis and its treatment in its earlier and active stage by the use of vaccines. The first attempt to treat the disease by staphylococcus albus vaccine was made in a case under my care at the Middlesex Hospital in 1909. The recurrent attacks of lymphangitis from which this patient suffered remained in abeyance for over a year after the cessation of treatment, though they had previously been frequent.

Vaccine treatment is uniformly followed in my experience by marked softening of the hard subcutaneous tissue. The diameter of the limb is not diminished by this treatment alone, but if massage is combined with it, and the case is not too far advanced, an improvement verging on cure may be obtained. In a recent case of lymphatic œdema of the thigh in a girl of twenty the swelling, though of ten years standing, practically disappeared after three months of vaccine treatment combined with massage. The circumference of the thigh diminished by more than six inches.

The vaccine should be given weekly by subcutaneous injection in the arm, in doses of 250 to 500 millions. A stock vaccine may be employed.

Owing to the rarity of the disease in England, my opportunities for treating it are restricted, but if tropical experience confirms my observations a great step will have been taken towards the eradication of this intractable and common disease. It is to be observed, however, that vaccine treatment cannot be expected to benefit advanced cases where the bacterial cause may be no longer active, and where only its results remain in the shape of vast deposits of indurated and sluggish subcutaneous tissue.

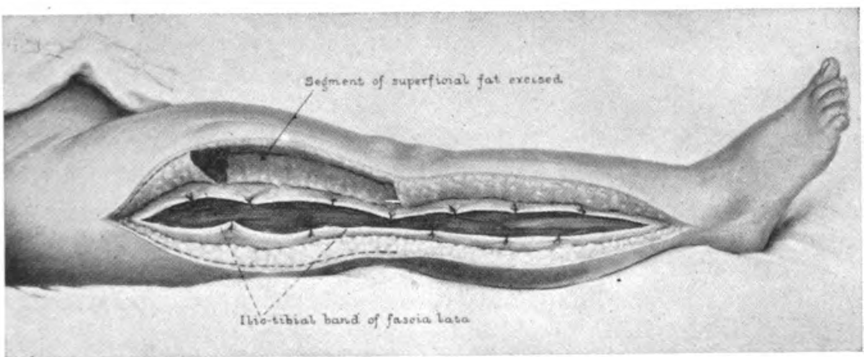

FIG. 224. ROGERS-KONDOLEON OPERATION. (*Sistrunk*)

The lymph vessels in cancer. In carcinoma and in melanotic sarcoma the lymph vessels are the principal channels for the diffusion of the disease. In an early stage of many malignant growths particles of the growth are swept along by the lymph stream to lodge in the nearest glands. Enlargement of the infected glands soon becomes obvious. Coincidently with embolism along the trunk lymphatics, cancer cells spread along the finer vessels of the lymphatic plexuses by the actual growth of minute plugs of cancer cells along the vessels. To this process the writer has applied the name permeation. It must be sharply distinguished from infiltration. Permeation spreads like a ripple in the plane of the lymphatic plexus into which the cancerous organ drains. Its slow centrifugal spread conducts cancer cells ultimately to the serous cavities, whereupon death follows the rapid diffusion of the growth. A knowledge of the laws governing permeation is essential in the operative treatment of malignant disease.[1]

[1] See Handley's *Cancer of the Breast and Its Operative Treatment* (London: John Murray).

Lymphatic œdema of the arm in breast cancer. In the course of breast cancer permeation and subsequent fibrosis of the lymphatic vessels about the shoulders, together with obstruction of the axillary glands by growth, may completely obstruct the return of lymph from the arm, which thereupon falls into a condition of solid lymphatic œdema. The arm becomes paralyzed and may be the seat of severe pain.

In the early stage of the disease elevation of the arm in an extended position upon an inclined plane may give temporary relief. Later this position cannot be borne, and in suitable cases great relief follows the writer's operation of lymphangioplasty or subcutaneous internal drainage by buried lines of silk. The swelling rapidly subsides, pain ceases, and function may return. These effects are usually permanent unless pleural effusion supervenes to interfere with drainage. Prior to the introduction of this method amputation of the arm was the only alternative to the habitual use of sedatives.

Benefits to be expected from lymphangioplasty. Before describing the operation I wish to state clearly that it is palliative only, and that it has no claims to prolong life or to modify the natural downward course of the disease. In favorable cases it has the following effects:

(1) Complete relief from pain within twenty-four hours, unless the pain is partially due to some cause—such as nerve pressure—independent of the œdema.

(2) A marked and rapid fall in the tissue tension of the whole area drained by the threads. The arm in consequence, instead of being hard and brawny, becomes abnormally soft and flabby. This may sometimes occur even though postural treatment is neglected, and in the absence of any marked diminution of the diameters of the arm.

(3) Rapid subsidence of the swelling, commencing immediately in the hand, and extending to the forearm within twenty-four hours. At first the upper arm is unaffected, or its diameters may even slightly increase. But within a week or two the diameters of the upper arm are also markedly lessened. The subsidence is usually permanent, unless and until pleural effusion supervenes to interfere with drainage. These effects are first dependent upon the adoption of proper postural after-treatment, but after a few months' elevation of the arm may be entirely abandoned without any marked increase of swelling.

(4) Return of power to the paralyzed arm if the paralysis is of recent date. If the paralysis is of more than a few months' standing, no return of power is to be expected.

(5) An improvement in the general condition, dependent partly upon relief from pain and its associated symptoms of insomnia and depression, and partly upon the abandonment of sedatives.

Technique of lymphangioplasty for brawny arm. The special materials necessary are a set of suitable probes, lymphangioplasty forceps with jaws specially designed to take a firm grip of either end of the probe, and a supply of No. 12 tubular woven silk.

The tissues of the arm are drained by two long U-shaped lines of silk, each line composed of two threads of No. 12 tubular silk. One of these lines drains the front of the arm, the other the back. The bend of each U lies immediately above the wrist, and its two limbs occupy respectively the radial and ulnar side of the limb. Thus, along the whole length of the limb are found four double lines of silk, spaced out round the limb as nearly as possible at quadrant intervals. Towards the shoulder the lines of silk on the flexor aspect curve outwards around the deltoid muscle, and converge to meet the ascending threads from the posterior border of the deltoid. From this point the silk threads again radiate in the subcutaneous tissue of the back, terminating by free ends in the subcutaneous tissue of the scapular region. It is, perhaps, still better to lead some of them to the scapular region of the opposite side, and others to the lumbar region of the same side, if there is any sign of the œdema extending from the arm to the trunk.

The operation is done as follows:

A double line of silk, rather more than twice as long as the arm, is marked at its midpoint by clipping on it a pair of artery forceps. One-half its length is wrapped in gauze. The two free ends of the other half are threaded through the eye of a long probe. An incision one-half an inch long is made through the skin at the middle of the front of the forearm, just above the wrist joint. The probe is thrust upwards in the subcutaneous tissues well away from the skin towards the region of the elbow. It is then withdrawn through an incision made over its point and the silk drawn after it as far as it will come. The probe is again introduced through the incision from which it has just emerged, thrust upwards again in the selected line, and the foregoing steps repeated until the point selected for the convergence of the threads is reached. Here an incision one inch long is made, through which the probe with its two silk threads is drawn out. The other half of the silk loop is now led upwards in the selected line along the other border of the flexor surface. The limb is turned over and the extensor loop of silk is similarly introduced. When this has been done eight free ends of silk are hanging out from the incision of convergence at the posterior border of the deltoid. Two at a time these are tucked away in various directions in the subcutaneous tissues of the back by the following manœuver.

A pair of forceps is clamped on the selected pair of silk threads just where it emerges from the topmost incision. The threads are threaded on a long probe, and the ends then cut so that the threads are four inches shorter than the probe. The probe is thrust downwards from the incision in the desired direction until it unthreads itself. It is then carefully withdrawn, leaving the two silk threads to occupy its track. When all the threads have thus been tucked away, the operation is completed by sewing up the incisions with horsehair or fine silkworm sutures. No drains are left in the wound.

The principal difficulties of the operation are connected with the maintenance of the silk in an aseptic condition. Owing to the large area dealt with, extending on to the back, the necessary changes in the posture of the arm, and the length of the silk threads, accidental contact may very easily occur between the silk and the surface of the skin, the edges of the incisions, or surrounding objects. I regard the use of masks as essential, and the silk ends not actually dealt with at the moment must be kept wrapped in sterile gauze, which is also useful to protect them from the edges of the incisions as they are being drawn in after the probe. This method contains modifications which my experience has shown to be desirable. My object has been to simplify the operation, to reduce the number of incisions necessary, and as a reasonable precaution to insert the threads in such a manner that they can, if necessary, be withdrawn with a minimum of trouble. All the threads can be withdrawn by reopening the two incisions just above the wrist. Fortunately I have never been obliged to do this. There is no need to fix the upper ends of the threads by knotting them together, as I formerly thought, for the silk soon becomes adherent along its whole length to the tissues in contact with it.

Cases of brawny arm may be grouped in the following categories:

(1) Cases in which a dropsical arm is the only manifestation of active disease.

(2) Cases complaining of severe pain in the arm with masses of growth, but without ulceration, pleural effusion, and nerve pain.

(3) Cases with axillary or thoracic ulceration but without pleural effusion.

(4) Cases in which enlarged supraclavicular glands are present.

(5) Cases with pleural fluid or other evidence of thoracic cancer.

Cases belonging to the first two groups, and some of those in the third group, are suitable for operation provided the scapular region is free from lymphatic œdema. Cases in groups 4 and 5 are unsuitable for operation.

The rationale of the operation of lymphangioplasty has been called in question by Cole, Madden, Ibrahim, and Ferguson.[1] Their experi-

[1] *Brit. M. J.*, Nov. 2, 1912.

ments on the guinea-pig showed the following changes in the buried threads:

(1) For a short time the threads, by virtue of their capillary action, drain the surrounding tissues of the lymph contained in them.

(2) The threads in the tissues soon excite a definite cellular reaction, which leads comparatively soon, after fourteen to twenty-one days, to the formation of a dense and progressively contracting fibrous tissue. This walls off the thread and crushes the adjacent lymphatics, and thus effectually prevents any absorption of fluid into the space immediately around the thread itself. These fibrous changes, occurring around the ends of the thread, as well as along its whole length, eventually completely isolate it, and it may then perhaps be compared to a long worm lying within an impermeable sheath.

(3) The thread is later penetrated by rows of cells, running in along its fibrils, which must eventually lead to its complete disintegration, and the formation of a solid column of dense fibrous tissue along which no absorption of fluid of any kind can possibly occur.

These pathological conclusions based on experiments with healthy animals, do not change the fact that in some way or other the operation produces considerable benefit in a proportion of suitable cases, perhaps by breaking a vicious circle. Its failure in other cases, also apparently suitable, tends to confirm Madden's conclusions. Of late years I have felt unable to urge the operation, while offering it as a probable means of relief.

The surgery of ascites. Since the serous cavities of the body may be regarded as lymphatic spaces, the surgery of ascites must receive a brief mention here.

It has been shown conclusively that when medical treatment and repeated tapping fail, certain cases of ascites, due to alcoholic cirrhosis or to visceral syphilis, may be actually cured, or relieved for a long period, by surgical measures. Those cases in which the ascites is dependent upon malignant disease, or where serious visceral disease is present, especially renal lesions, or where the ascitic fluid is being secreted with excessive rapidity, are unsuitable for surgical treatment. The methods which have been used fall into two classes: those which aim at diverting the obstructed portal blood stream into the systemic circulation, and those which act by helping the absorption of ascitic fluid. Of the first group the Talma-Morison operation is the most satisfactory.

The Talma-Morison operation for ascites consists in the implantation of the omentum upon the parietal peritoneum of the anterior abdominal wall. New vessels form in the adhesions and blood is carried from the omental veins into the epigastric veins. Subsequent to the operation the latter veins may become enlarged. Though successful in a proportion of cases, the operation is not free from danger. Toxic symptoms may arise from the diversion of unfiltered portal blood into the general system.

The methods which act by helping the absorption of the ascitic fluid include (a) Wynter's operation and (b) lymphangioplasty.

(a) In the operation of femoral drainage (Wynter's operation) which was first carried out by the writer, the femoral canal is exposed below Poupart's ligament and divided with scissors; the two halves of the canal are then sutured to Poupart's ligament, so as to maintain the patency of the opening. The ascitic fluid escapes into the cellular tissue of the thigh, and is re-absorbed by the lymphatics. The operation is simple and safe. It appears to be the operation of choice in ascites, but it is liable to fail, from blocking of the opening either by a piece of omentum, or later by the process of cicatrization. A number of cases of permanent cure already stand to the credit of this method, and within the last six months, in association with Dr. Burnford, the writer has operated on two cases with most satisfactory results.

The only difficulty in femoral drainage is that of finding the femoral canal. The abdomen bulges downwards over Scarpa's triangle, and the canal itself appears to be drawn up under Poupart's ligament by the tension of the peritoneal fluid, and perhaps by contraction of the peritoneum from chronic inflammation. The special instruments required for operation are a large-sized curved trocar and cannula, and a long blunt-pointed seeker, curved so as to pass through the cannula. The peritoneal cavity is tapped in the midline about two inches above the pubes. The trocar is withdrawn and the long seeker inserted through the cannula, which it fits fairly closely. By a flap incision with its convexity directed outwards, the region of the femoral ring is exposed. With the aid of the seeker the situation of the femoral ring is located and the seeker pushed into it, thus making the femoral canal bulge into the floor of the femoral wound. With two pairs of artery forceps the peritoneum of the femoral canal is seized on either side of the point of the seeker, and freely divided between the forceps with a pair of scissors. A large amount of ascitic fluid escapes, but no special effort need be made to empty the abdomen. Two sutures are introduced, one on either side of the opening, each taking up the peritoneum and passing through Poupart's ligament. The sutures when tied serve to secure the patency of the new opening. Finally the skin incision is sutured.

(b) The writer's operation of lymphangioplasty can be adapted to the treatment of ascites. It is to be recommended in cases where the simpler operation of femoral drainage has failed and where the fluid is being secreted with only moderate rapidity.

Solid œdema dating from early life. Under this heading may be grouped a collection of heterogeneous cases, in which there is a more or less solid œdema of one or both feet, extending a variable distance up the limb, which is not due to any traceable infection, is unaccompanied by visceral disease and tends, if uncontrolled, to become progressively worse. The condition may be congenital, or may begin in infancy or childhood. In certain cases of this group, the disease is hereditary, and has been given the name of Milroy's disease. Family histories of this type have been placed on record not only by Milroy, but by Dr. H. D. Rolleston, Drs. Hope and French, Dr. G. A. Sutherland, and Dr. W. Bullock. The disease is generally held to be caused by vasomotor disturbance, and to be closely related to angioneurotic œdema. One of Dr. Sutherland's cases had suffered from purpura and urticaria.

Cases may be met with which differ from Milroy's disease only in the absence of the hereditary element. Two such cases have been submitted to lymphangioplasty, one by Dr. P. P. Busch, and one by myself, in both cases without benefit.

Solid œdema following septic wounds. Cellulitis following a septic wound is sometimes followed by persistent brawny œdema, presumably due to associated lymphangitis and subsequent lymphatic obstruction. It is very doubtful whether such cases are suitable for lymphangioplasty, for phlebitis and venous obstruction are usually also present.

In March, 1909, Dr. H. R. Mansell, of Hastings, asked me to see a lady with a view to possible lymphangioplasty. On December 24, 1908, she ran a needle into her hand, and the following day the end of the needle was excised. The wound healed by first intention, but there was acute pain and swelling of the forearm for three weeks subsequently without any pyrexia or suppuration. The back of the hand and wrist assumed a blackish-blue color. There was more tenderness over the basilic vein, but no definite hardness along it to indicate phlebitis. Pain had disappeared, but much stiffness and brawny swelling of the fingers and hand remained.

While I agreed with Dr. Mansell's diagnosis of chronic septic lymphangitis following a septic needle puncture, I felt that there was also a phlebitic or cellulitic element in the case. Feeling that the benefit of lymphangioplasty was doubtful, and as the condition was improving, I advised against operation.

Puerperal "white leg." Although until recently I hoped that lymphangioplasty would be of benefit in puerperal white leg, I had always felt that the almost invariable presence of an element of venous obstruction made the question a very doubtful one. And although several such cases have been referred to me for the operation I have not found among them one which I considered favorable for the first essay. At the present time, and in view of the failure of the operation for elephantiasis of the leg, I am of the opinion that lymphangioplasty is not applicable in such cases.

Solid œdema due to chronic renal disease. From a pathological point of view it is interesting to note that long-standing œdema from chronic tubular nephritis may produce in the legs many of the changes characteristic of elephantiasis, as in the following case:

F., a man aged 22, was admitted under my care with a view to the possibility of lymphangioplasty. When nine years of age swelling of the ankles commenced, and increased progressively thereafter. Eleven years later the hands began to swell. On admission the legs and feet were much swollen, but the œdema pitted slightly on pressure. The face also swelled if his head was lowered, and the lumbar region as he lay in bed. Elevation of the part affected soon reduced the œdema. The urine contained 4.5 per cent of albumen. The skin of the swollen legs showed the characteristic changes of elephantiasis, especially on the feet. Between the toes the skin was in a remarkable condition, being uniformly covered with somewhat pointed papillary eminences like an exceedingly coarse velvet.

Solid œdema due to syphilis. My senior colleague, Dr. J. J. Pringle, sent to me some years ago a case which appears to show that tertiary syphilis may cause lymphatic œdema and all the changes characteristic of elephantiasis. The presence of foul gummatous ulcers upon the thickened skin deterred me from attempting operation, and present experience shows that it would have been useless. Subcutaneous gummata are most commonly found upon the leg, between the knee and the top of the boot, and in association with varicose veins. Less commonly they extend to the thigh. These facts point to deficient lymphatic circulation as a predisposing cause. In a case of ascites operated upon by me in which the left leg was used as a sewage farm to absorb the ascitic fluid, a crop of gummata developed, while the right leg remained free. The maintenance of an active lymphatic circulation by habitual exercise and plain living must therefore be regarded as important in the prophylaxis of tertiary syphilitic lesions.

Lymphangiomata are tumors mainly composed of lymphatic vessels. On account of their rarity they possess little importance. They are of two varieties: (a) the capillary lymphangioma or lymphatic nævus, a yellowish, slightly raised, congenital, sharply defined area of skin, distinguished by its color from the ordinary hæmic capillary nævus; (b) the cavernous lymphangioma (cystic hygroma) which is a multilocular, fluctuating swelling occurring in the subcutaneous tissues. Its spaces contain clear lymph and are dilated lymphatic vessels or spaces. It occurs most commonly in the neck or axilla, during the first decade of life.

Lymphangiomata are usually best treated by excision.

Septic lymphadenitis. When a local focus of pyogenic infection is present the corresponding lymphatic glands frequently become inflamed. Most commonly the septic focus is found in the naso-pharynx, and the cervical glands are accordingly affected—a common complication of the exanthems of childhood. Pediculosis or eczema of the scalp and alveolar abscess are also frequent causes of septic cervical glands. Often the glands in the groin or in the axilla are affected, usually as the result of a "poisoned wound" on the foot or hand. The healing of the primary focus of infection may precede, sometimes by months or years, the evolution of the secondary lymphadenitis. That is to say, bacteria may remain latent in lymphatic glands for long periods until circumstances favor their attack.

At first the glands are enlarged, firm, mobile, and tender. If the affection then subsides the tenderness disappears and the glands slowly return to their normal size. But often suppuration takes place. It is preceded by fixation of the gland from peri-adenitis. The skin becomes adherent, thinned, and erythematous, fluctuation is manifest, and the abscess bursts, leaving a sinus which is sometimes very persistent.

The primary focus must be sought for and treated. Hot fomentations of glycerine or belladonna may be applied to the glands in the early stage. Suppuration requires incision, followed by treatment with Bier's suction glasses.

Bubo is a chronic suppurative inflammation of the glands in the groin, secondary to the presence of soft venereal sores upon the genitals. It is more common in men than in women. The skin over the tender and inflamed glands becomes reddened and gives way. An obstinate sinus is left which may continue to discharge for months.

The soft sores must be treated by antiseptic lotions and dusting powder. In the early stage hot fomentations may be applied to the glands, or a mixture of mercurial and belladonna ointment may be rubbed into the skin. As soon as pus forms it must be let out by a vertical incision. A horizontal incision gapes and heals badly. The only method to secure a rapid cure is completely to excise the affected glands. If they have already broken down so that the operative infection of the tissues is likely, the cavity left must be packed with sulphur and gauze for twenty-four hours. Subsequently the cavity is irrigated with boracic lotion and fomented until the sloughs caused by the sulphur have separated. If precautions are taken against reinfection the cavity remains an aseptic wound and heals rapidly.

Syphilitic lymphadenitis. In the early stage of syphilis the glands into which the primary sore pours its lymph become infected. They are enlarged and hard but remain discrete and painless. In the secondary stage, when the infection has become systemic and general, all the accessible glands of the body share to a less extent in the enlargement. Syphilitic glands never suppurate, and require no independent treatment.

Tuberculous lymphadenitis. Tuberculous glands of the neck are among the commonest affections of childhood, while in adults they are comparatively rare. It is of the highest importance to recognize the facts recently established by Stiles and his fellow-workers in Edinburgh. They have shown by laborious investigations that many cases of tuberculous glands in the neck and other tuberculous lesions in childhood arise in houses where no human case of tuberculosis is present, the inference being that the source of infection is bovine and probably traceable to milk.

In order to prove the point it was necessary to determine in a number of cases of infantile tubercle whether the bacillus was bovine or human. The distinction is possible owing to the fact that experimental animals do not react in the same way to the human bacillus as to that of bovine origin. Working on these lines it has been absolutely proved that a majority of cases of infantile tubercle are due to bovine infection, which broadly speaking means milk infection. The most recent investigations of Dr. A. S. Griffith[1] show that in childhood cervical-gland tuberculosis is caused more frequently by the bovine than by the human type of tubercle bacillus, nearly three-quarters (72.1 per cent) of the cases in children under 10 years of age having yielded bovine tubercle bacilli. In persons over 10 years of age infection of human origin is more common, bovine infection accounting for about a third of the cases in the second decade, and for rather less than a fifth of the cases in persons over 20 years of age.

In view of these well-established facts it is probable that a proper system of milk supervision would permit half the children's hospitals in this country to be closed. The matter urgently requires legislative attention. The point of entry of the bacilli is in nearly all cases the ring of lymphoid tissues which surrounds the fauces; that is to say, either through adenoid vegetations of the naso-pharynx or by way of the tonsils. Tubercle bacilli have frequently been found in excised tonsils and adenoids.

It is frequently stated that infection may occur through carious teeth, but I believe this is erroneous. Dental infection may, however, cause tuberculous glands to suppurate which would not otherwise have done so.

In nearly all cases tuberculous enlargement is first evident in a gland

[1]See Handley's *Cancer of the Breast and Its Operative Treatment* (London: John Murray).

situated just at the angle of the jaw on either side. The enlargement is bilateral, but the gland on one side is larger than that on the other. This asymmetrically bilateral character is preserved as the disease advances. The glands along the carotid sheath are first affected. Thence the infection may spread into two side-chains of glands, one, situated in the submaxillary triangle; the other, passing downwards and backwards across the posterior triangle, and ultimately reaching the axilla. The occipital glands also become infected in certain cases.

As the disease advances the glands first affected may soften and caseate. The skin over them becomes adherent and reddened, and an abscess forms, which after bursting leaves an obstinate tuberculous sinus. The adjoining skin may show lupoid infection. Tuberculous glands are rarely dangerous to life, nor do they often lead to phthisis or to general tuberculosis. They usually disappear before adult life is reached. They may, however, first develop in adult life, and even in old age. Often rational nonoperative treatment averts suppuration.

The proper control of milk supplies and the exclusion by the tuberculin test of all tuberculous cows would probably bring about an enormous reduction in the frequency of tuberculous glands. If tuberculin-tested milk is not available the milk should be pasteurized or boiled, but both of these methods impair its nutritive value for the child and are therefore unsatisfactory.

The second important element in prevention is the maintenance of the naso-pharynx in an aseptic condition. While it is customary to clean a child's teeth daily, as a rule no attention is paid to the naso-pharynx, which, in cities at any rate, must be the receptacle for a large amount of dirt and many bacteria from the air. The fact that apparently healthy children may harbor malignant organisms, such as diphtheria bacilli or meningococci, in the naso-pharynx has been proven beyond a doubt.

In my opinion the naso-pharynx of all town-bred children should be washed out daily with a weak antiseptic. Probably the best preparation is an alkaline solution of thymol. About ten drops of the solution should be instilled into each nostril night and morning by a nasal douche, or by an ordinary fountain-pen filler. Children do not object to this process, and indeed come to like it. If the tonsils are large they should be separately painted with glycerine and boracic acid daily. In my opinion these simple preventive methods, which are carried out daily in my own household, would not only decrease the frequency of tonsillar enlargements, adenoids, and tuberculous glands, but would also greatly diminish the incidence of the acute infections such as scarlet fever, measles, and acute rheumatism.

Tuberculin treatment has its advocates, but personally I have never been able to convince myself of its value. It must be remembered that in many cases a secondary pyogenic infection is present. Medicinal treatment is of limited value, but a syrup of iodide of iron undoubtedly does good in many cases, while if the child is thin, cod-liver oil must be administered. Operative treatment should not be resorted to as a routine, nor, on the other hand, should it be too long deferred. If the glands show signs of breaking down it is probably best to excise the whole of the affected glands, and not merely to open and scrape those which are actually softened. The operation required is a delicate and somewhat difficult one and should only be undertaken by a practised surgeon, for it usually involves opening the carotid sheath, while the spinal accessory nerve frequently runs between two of the enlarged glands and may be firmly imbedded in a mass of fibrous tissue. (The technique of excision of tuberculous glands of the neck is described in Section III, Volume III.)

Lymphadenoma (Hodgkin's disease) is variously regarded as an infection by an unknown organism, or with greater probability as a malignant neoplasm of lymphatic glands. It affects by preference young adult males, though it may occur at any age. Sometimes the patient gives a history of a pyogenic infection in the area served by the diseased glands, a fact which has given color to the infection theory of the origin of lymphadenoma. The disease is local in its origin, affecting at first a single group of glands, most often the cervical ones. It spreads gradually to the adjoining sets of glands and may finally involve the lymphoid tissue all over the body. The spleen is enlarged in the later stages and shows on section the characteristic appearance of almond toffee (hard-baked spleen) from local deposits of lymphadenomatous tissue. The liver and kidneys may show similar deposits. The blood, at first unaffected, in a late stage shows merely the appearances of secondary anæmia. Death is usually due to circulatory disturbances produced by the pressure of enlarged deep glands upon the veins, or to respiratory difficulties of similar origin.

The question as to the wisest method of treatment is one that has not yet been definitely answered. The best recorded results are those of Yates and Bunting (*J. Am. M. Ass.*, 1917, lxvii, 747; *Surg., Gynec. & Obst.*, 1918, xxvii, 156) who reported a series of 63 cases including 5 acute and 58 chronic cases. Of the chronic cases 12 were considered as cured after intervals varying from six months to five years; 8 were much improved, though the improvement was not permanent; a further number were temporarily relieved of their symptoms. Though apparently this constitutes a low percentage of cases showing recovery from the disease one must remember that, although temporary remissions are common, recorded cases of absolute recovery have been extremely rare, and many cases of reported recovery following various forms of treatment have in fact been only remissions of the disease, perhaps even remissions such as so frequently occur without any treatment whatever.

Bunting and Yates emphasize first of all the importance of removing every possible focus of infection, in particular those which occur about the mouth, throat, and in the skin.

The second step in the treatment consists of the complete removal of the affected tissue, with particular attention to the fatty gland-bearing tissue. For example in the dissection of the neck the authors make an incision from one inch back of the mastoid process down to the clavicle, and raise the superficial tissues of the skin in a single flap to a point well beyond the midline. The deep fascia, glands, and fatty tissue are carefully removed. The authors emphasize the importance of removing the submaxillary lymphatic glands, the glands in the lower portion of the parotid, the mastoid lymph gland, and the fatty tissues and glands both in front of and behind the anterior portion of the trapezius. They raise the great vessels of the neck, and resect the fatty tissue and glands underlying them to a point below the junction of the internal jugular and subclavian veins. At times the entire sternocleidomastoid is removed, with the fatty tissue underlying both its origin and insertion. The dissection of the diseased tissue in the other regions commonly involved is carried out in the same thorough manner. The dissection of the axilla commonly involves the complete removal of the pectoral muscles, and the lateral portion of the mammary gland. The dissection of the groin involves the removal of the fascia lata from the anterior surface of the upper third of the thigh, and of the fatty, gland-bearing tissue along the iliac vessels from Poupart's ligament to the sacrum.

At the conclusion of operation and at intervals thereafter the wound is exposed to X-ray treatment. Vaccine treatment is carried out at the same time, so as to leave undone nothing that might in any way conduce to ultimate recovery.

Lymphatic leukæmia simulates Hodgkin's disease, but presents in addition the characteristic blood changes of leukæmia. It requires merely to be mentioned here, since it is a blood disease, and not primarily a disease of the glands.

Lymphosarcoma. Primary sarcoma of the lymph glands is a rare and hopeless disease, affecting the glands of the axilla, the neck, the mediastinum, or the mesentery. Commencing in one gland or group of glands, it rapidly extends to the neighboring groups. Meantime the glands first affected increase rapidly in size and become adherent to the skin and surrounding tissue. The overlying skin ulcerates and a mass of sarcomatous tissue protrudes. The course of the disease is very rapid, and death usually occurs from pressure upon vital organs. If lymphosarcoma is in most cases a hopeless condition, this rule is not invariable.

I recently saw a man of about 50 with a fixed mass in the axilla after an operation for lymphosarcoma of the axillary glands. The mass was adherent to the axillary vein, but I was able to remove it after resecting the vein. Shortly after, enlarged glands made their appearance in the left posterior triangle. These were thoroughly cleared out from the mastoid process to the clavicle, and a large gland was enucleated from behind the sternum. Subsequently X-rays were vigorously applied to the region of both operations, and on half a dozen occasions local nodular recurrences in the neck and the scapular region were dealt with successfully by means of radium. The patient three years afterwards was free from recurrences and is at present holding an important military command.

Lymphosarcoma is such a malignant form of neoplasm that a diagnosis can rarely be arrived at before the case has become inoperable.

If the disease is confined to one group of glands of the neck the whole of the lymphatic glands in the neck and axilla on the affected side should, as far as possible, be removed. This applies to apparently healthy glands as well as to those obviously diseased, for beyond the latter it is certain that there is a zone of glands microscopically infected. If, as nearly always happens, operation is impossible, treatment by Coley's fluid appears to be the best resource.

Diagnosis of cervical glandular enlargements. It is sometimes very difficult to distinguish between glandular enlargement due to tuberculous infection and that which so frequently results from nasopharyngeal sepsis occurring in the acute exanthems of childhood. Frequently the diagnosis can only be made by watching the case. If the enlargement is due to septic organisms, the glands are tender, and they either usually break down rapidly and suppurate, or they disappear. If the glands remain enlarged after they have ceased to be tender, the probability is that tuberculous infection is present. Swellings due to tuberculous infection of the glands at the angle of the jaw may be so sudden in their onset that the diagnosis of mumps may suggest itself, but the swelling in mumps extends upwards behind the ramus of the jaw, and there is difficulty and pain in mastication. The diagnosis of tuberculous glands from lymphadenoma also presents difficulties. Lymphadenomatous glands are usually large, elastic, and mobile, presenting no tendency to softening or suppuration, while tuberculous glands are often more fixed and of smaller size, and if they attain any considerable size softening or fluctuation can usually be detected. It must, however, be recognized that tuberculous glands may sometimes present all the characters described as typical of lymphadenomatous glands. In the writer's opinion the most trustworthy distinction between these two forms of enlargement is the distribution of the glands. It has already been stated that tuberculous glands are nearly always asymmetrically bilateral; that is to say, if glands are present on one side of the neck, a less marked degree of enlargement will also be found upon the opposite side. On the contrary, in the early stage of lymphadenoma the disease is strictly unilateral and confined to one set of glands. It is sometimes stated that enlargement of the glands in the axilla, coincident with enlargement of the glands in the neck, points to lymphadenoma rather than to tubercle. This statement, however, is erroneous, for I have often observed tuberculous enlargement of the axillary glands co-existent with tuberculous enlargement of the cervical glands. From leukæmia tuberculous adenitis can easily be distinguished by an examination of the blood, which in the case of leukæmia will show an enormous increase in the number of white corpuscles. Lymphosarcoma, like lymphadenoma, is unilateral in its early stages. The enlargement of the glands is much more rapid than in the case of tubercle. The sarcomatous glands, unlike those of lymphadenoma, soon become adherent to their surroundings by infiltration. They adhere also to the skin, which may ulcerate, with the formation of a fungating mass of growth. The patient rapidly goes downhill, signs of thoracic metastases develop, and death comes quickly.

Enlarged cervical glands, while common in early life, are rarer in the adult. In those beyond middle life carcinoma is the commonest cause. It must not be forgotten that enlarged left supraclavicular glands may be an early sign of gastric carcinoma.

In all cases of glandular enlargement a thorough search for a primary infective focus should be made. The presence of eczema of the scalp, pediculi, carious teeth or otorrhœa, or in older patients of a malignant growth, may render the disease obvious.

SECTION V

OPERATIONS UPON NERVES

PLASTIC OPERATIONS UPON NERVES

BY

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OPERATIONS UPON THE CRANIAL NERVES AND THE GASSERIAN GANGLION

OPERATIONS UPON THE NERVES OF THE EXTREMITIES

BY

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CHAPTER I

PLASTIC OPERATIONS UPON NERVES

THE function of a peripheral nerve may be interfered with or completely suspended as the result of compression by scar tissue, bony callus, or adhesions, without an interruption of continuity. This suspension is called physiologic interruption, in contradistinction to anatomic interruption, which is associated with solution of continuity of the nerve trunk. It is often impossible to differentiate clinically between physiologic and anatomic interruption, and the pathologic condition which suspends the function of the nerve can be determined only by operation.

In a discussion of peripheral nerve surgery the following operations must be considered: neurolysis; nerve suture; nerve transplantation; nerve grafting; tubulization.

NEUROLYSIS

Neurolysis is an operation which consists of dissecting the affected nerve out of the scar tissue or bony callus which compresses it, and of providing a new bed for it, or surrounding it with some material with the view of preventing the re-formation of scar tissue. It is often necessary in this operation to dissect away the thickened sheath of the nerve with the adherent scar tissue. This operation is referred to as capsulectomy. In cases in which there is a spindle-like thickening of the nerve without any evidence of solution of continuity, it is often advisable to make three or four parallel incisions in the thickened epineurium, with a view of lessening the compression and of favoring the downgrowth of neurofibrillæ.

Neurolysis was first performed by Busch and Ollier in 1863. Busch performed neurolysis upon a nerve which was compressed by scar tissue, and Ollier dissected a nerve out of bony callus which compressed it.

All surgeons are not agreed as to the value of neurolysis. Tinel states that neurolysis consists of liberation of the nerve and the removal of causes of compression—bony callus, scar tissue, cicatricial bands. According to him it is better to perform a nerve suture in doubtful cases than to be satisfied with a poor neurolysis. Delangenière is doubtful as to the value of neurolysis. He has done relatively few,

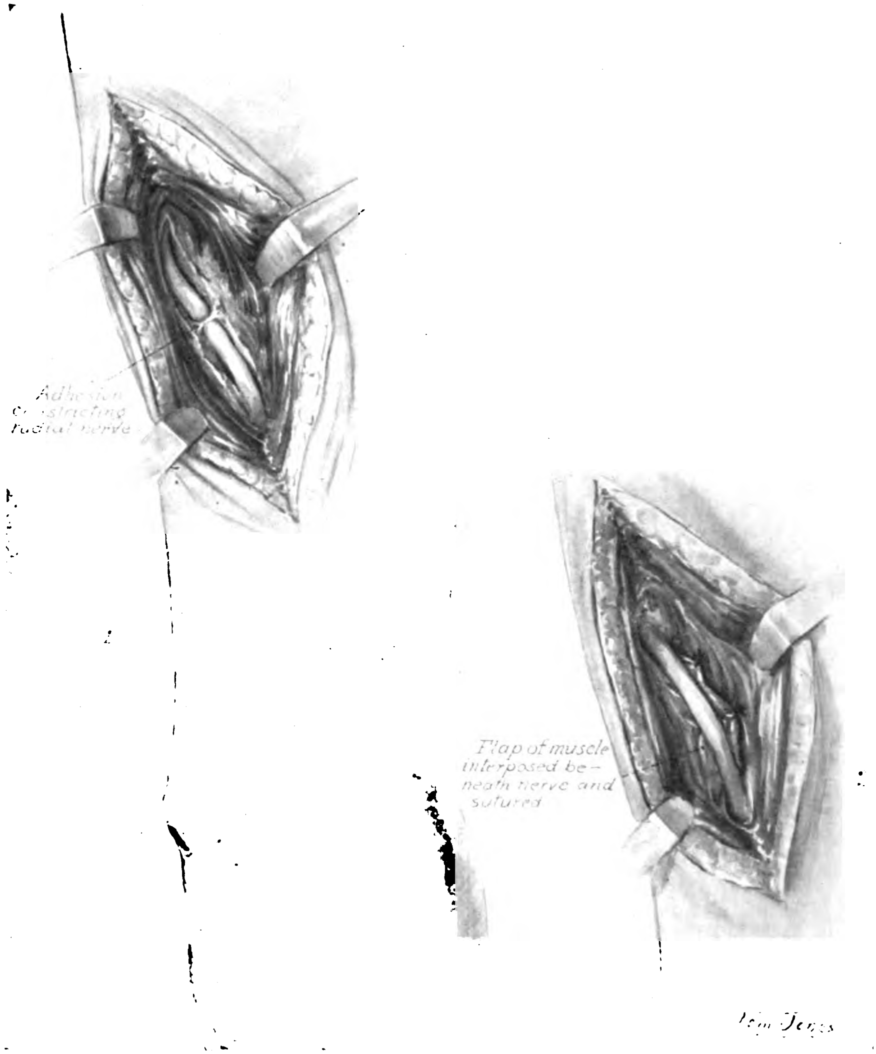

FIG. 225a. NEUROLYSIS. 1, Physiologic interruption of the musculospiral nerve by a constricting band of scar tissue. 2, Uninjured muscle sutured beneath nerve (the nerve will also be covered anteriorly by uninjured muscle). (*From the Surgical Clinics of Chicago.*)

because it has seemed to him that the cases do not do much better after neurolysis than they do when let alone.

The disagreement as to the value of this operation is undoubtedly due to its employment in cases in which it has not been indicated. The operation is indicated in those cases in which the lesion is extraneural, and the interference with or suspension of the function of the nerve is due to compression by scar tissue, or bony callus, or to adhesions between the nerve and surrounding structures. It should not be employed where there has been an actual solution of continuity of the nerve, unless combined with nerve suture.

In exposing the affected nerve the dissection should be made when possible along intermuscular septa, with the view of preventing hæmorrhage and avoiding the cutting of muscle fibers. After the nerve is freed a new bed must be provided for it, and whenever possible adjacent uninjured muscles should be used to make this bed. When muscle fibers are cut oozing occurs, and new adhesions, which may interfere with the function of the liberated nerve, form again about the nerve when placed in contact with cut muscle fibers. Uninjured neighboring muscles form the best bed for a liberated nerve and should be used whenever possible.

In many cases in which this operation is indicated, large amounts of scar tissue are found, and some other method of preventing the re-formation of scar tissue and adhesions about the nerve must be resorted to. Various materials, such as decalcified bone tubules, silk protective, hardened blood vessels, human epidermis, magnesium tubules, hardened gelatin tubules, Cargile membrane, fascia, fat, etc., have been employed to surround the liberated nerve, with the view of preventing the formation of scar tissue. Many of these have been discarded, and at present but three, Cargile membrane, free or pedunculated fat transplants, and blood vessels hardened in formalin (Foramitti's method), are used to any extent in surrounding the liberated nerve. Cargile membrane comes in various thicknesses. The thinner varieties should be used when neurolysis is performed. In cases which have been explored some months after the thicker varieties have been used, the membrane has been found in the tissues acting as a foreign body. The thinner varieties of the membrane are apparently absorbed in six months or somewhat less. During this time it has served its purpose in protecting the liberated nerve from compression by scar tissue and the formation of adhesions. Cone states that Cargile membrane is impervious to neurofibrillæ. It may therefore prevent, when placed about a liberated nerve, the straying of neurofibrillæ into surrounding tissue.

Some time ago fat transplants, either free or pedunculated, were used rather extensively about liberated nerves to prevent the formation of scar tissue. It has been claimed recently that they have but little value in this connection, and that they may even do harm. These claims are based upon the assertion that fat when transplanted does not remain as fat, but is replaced by connective tissue, and that transplanted fat may interfere with vascularization of the nerve. Rehn's experimental work would seem to indicate that transplanted fat survives. The vas-

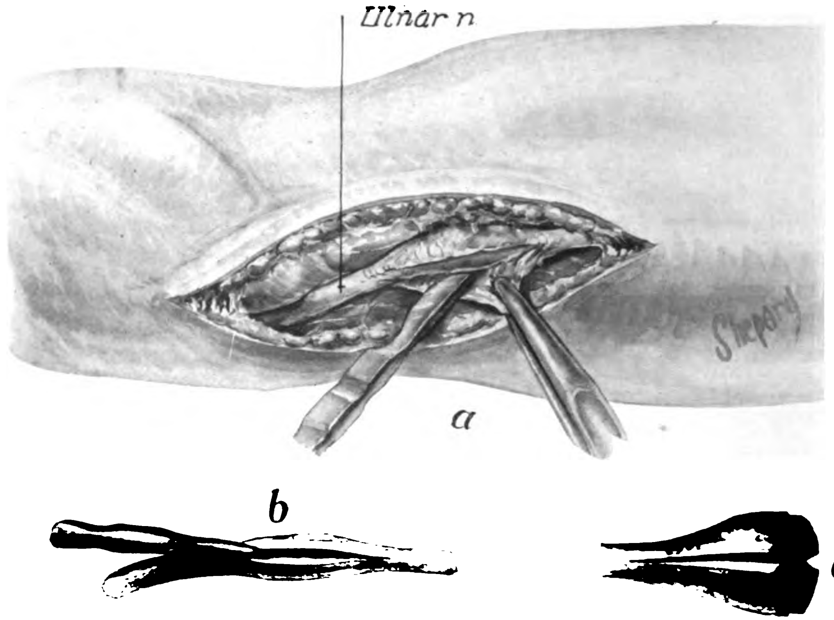

FIG. 225b. CAPSULECTOMY. *a*, Removal of thickened sheath of nerve with adherent scar tissue. *b*, Parallel incision of thickened epineurium in cases with a spindle-shaped enlargement without interruption of continuity. *c*, Appearance on cross-section after epineural incisions have been made.

cularization of the nerve would not be seriously interfered with unless very long stretches were surrounded by the fat.

Foramitti's method, blood vessels hardened in 10 per cent formalin, was used by Hashimoto in cases of nerve injury observed after the Russo-Japanese War. Neurolysis was performed in 43 cases. The results were very good in 10 cases, good in 15, satisfactory in 3, questionable in 4, and unsatisfactory in 11. In 7 cases neurolysis was attempted 300 days or more after the injury. In this series the results were good in 4 cases, questionable in 1, and unsatisfactory in 2. In 43 cases treated by neurolysis good results were obtained in 65 per cent, or if 4 questionable cases are included, in 74.4 per cent. The results obtained by neurolysis, performed 200 days after the time of injury, were doubtful. Hashimoto used almost exclusively calves' arteries hardened in formalin to surround the liberated nerve.

It has been advised that fascia be used for neurolysis. It has a very limited use for this purpose. In almost all instances in which neurolysis is indicated there is scar tissue. Transplanted fascia placed in contact with scar tissue undergoes contraction. Placed about a nerve under these conditions it would merely aggravate the condition which the operation is designed to relieve.

As previously mentioned, liberation of the nerve must often be combined with removal of the thickened sheath of the nerve and the adherent scar tissue, and incision of the thickened epineurium which covers the spindle-shaped enlargement of the nerve.

Neurolysis is often of distinct value in cases of physiologic interruption of a nerve, with or without degeneration in the segment distal to the point of injury. It can also be used to advantage in cases in which pain is the chief symptom, and in causalgia.

NERVE SUTURE; NEURORRHAPHY

Nerve suture is required when there has been a solution of continuity, partial or complete, of a nerve. If there has been an actual loss of substance of a nerve trunk, so that end-to-end suture of the segments is not possible, other procedures, which will be described later, must be resorted to. If the nerve is sutured immediately or shortly after the injury, the operation is referred to as primary nerve suture; when it is sutured some time after the injury, as secondary nerve suture.

Primary nerve suture. Primary nerve suture should be attempted in almost all instances after nerves are divided. It is required for the repair of nerves divided in incised and gunshot wounds; for the repair of nerves accidentally cut during operations, such as the spinal accessory in removal of tuberculous glands of the neck; and for the repair of subcutaneous lacerations of a nerve, such as occur in fractures or from overstretching.

Nerve suture is frequently not attempted in recent injuries because of danger of infection. Suppuration developing in a wound will prevent repair of the nerve at the line of suture. If suppuration does occur, nothing has been lost, for secondary suture can be attempted later; and the sutures inserted in the primary operation will keep the ends of the segments in fairly accurate apposition, so that they may be found more readily when the secondary suture is performed.

In performing primary suture one should remove the contused part of the nerve, so that healthy neurofibrillæ may be approximated. In incised, fairly clean wounds but little of the ends of the segments will have to be removed. When the division is due to a bullet or fragment of high explosive, the nerve is infiltrated with blood, and the nerve tissue is softened for some distance on either side of the point of division. This infiltrated and softened tissue must be removed before end-to-end suture is attempted; otherwise a spindle-like enlargement of scar tissue

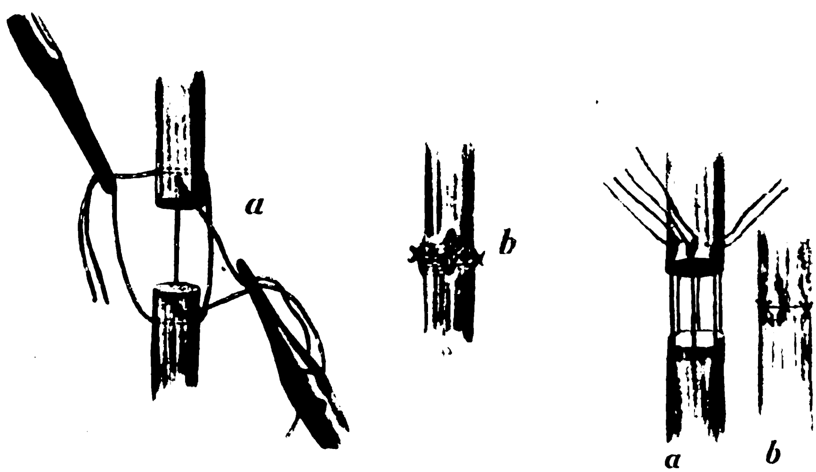

FIG. 226. NERVE SUTURE. *a*, Method of applying tension sutures. *b*, Epineurium closed by fine catgut or silk to prevent the straying of neurofibrillæ into surrounding tissues.

will form which may be impermeable to neurofibrillæ, and neurotization of the distal segment may thus be prevented.

Fine (No. 000 chromic) catgut is to be preferred in primary nerve suture. The ends may be approximated by four to six epineural sutures, or these may be combined with two transfixion sutures. These transfixion sutures are regarded as essential by many in order to avoid a dead space at the center of the nerve which may fill with a small blood clot. A blood clot interferes with nerve repair. If epineural sutures are correctly and accurately applied, this dead space will be avoided. The epineurium should be closed to prevent the straying of developing neurofibrillæ.

The sutures when tied should coapt the two ends of the nerve. They should not be crushed together, and tension should be avoided. Even in primary suture it is often impossible to coapt the nerve ends unless the extremity is placed in a position which relaxes the two segments. The parts should be fixed in a cast during the process of repair, so that no tension is placed upon the line of suture. In case of the median or ulnar nerves, fixation will be required for from four to six weeks; in case of the sciatic from six to eight weeks.

The after-treatment which should be instituted in these cases will be discussed under secondary nerve suture.

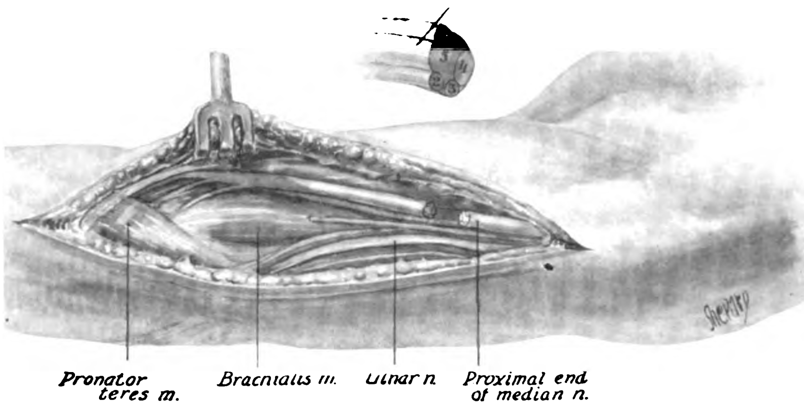

FIG. 227. INTERNAL TOPOGRAPHY OF THE MEDIAN NERVE. Cross-section shows the arrangement of the funiculi as follows: 1, tract for the pronator radii teres, flexor carpi radialis, and palmaris longus; 2, 3, tracts for the flexor sublimis digitorum; 4, tract for the flexor profundus digitorum and flexor longus pollicis; 5, sensory tracts and tracts to the muscles of the thenar eminence and first and second lumbricales. (*Vulpius and Stoffel.*)

Secondary nerve suture. When secondary nerve suture is attempted, pathologic conditions are usually found which render certain procedures necessary. During the process of healing, scar tissue will have developed. This varies according to the character of the wound. A small amount will be found in incised wounds, while in contused or gunshot wounds scar tissue may be extensive. A neuroma, composed of developing neurofibrillæ and scar tissue, will usually be found on the distal end of the proximal segment, and the proximal end of the distal segment will be found imbedded in a scar.

In exposing the two ends of the nerve one should begin the dissection at points where the anatomical relations of the nerve are still

FIG. 228a. NERVE SUTURE. Division of great sciatic nerve. (*From the Surgical Clinics of Chicago.*)

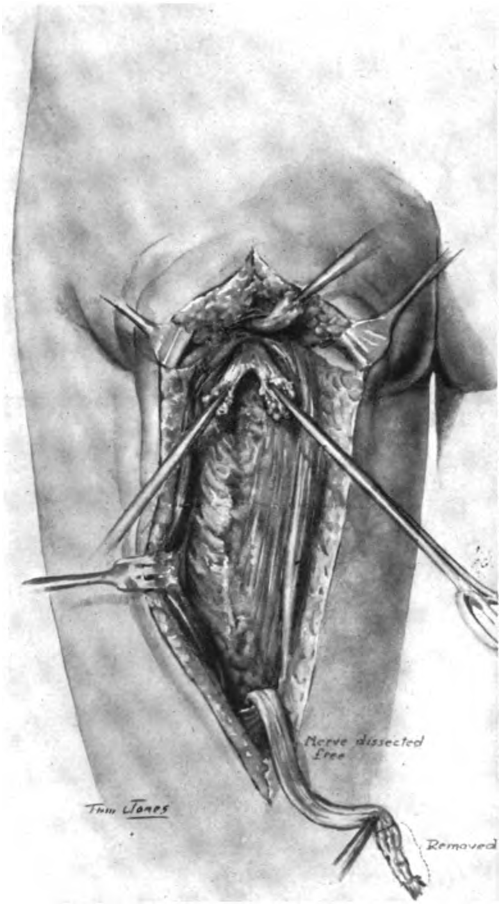

FIG. 228b. NERVE SUTURE. Method of traction on scar tissue and neuroma while attempting to approximate ends. Traction should always be made on tissue which is to be removed when the suture is made. Lower segment of sciatic nerve has been mobilized in order that an end-to-end suture may be made. (*From the Surgical Clinics of Chicago.*)

preserved. The nerve segments should be exposed above and below the point of division, and then should be carefully exposed to the point of division. When the ends are exposed, they should be grasped with artery forceps and an attempt should be made to approximate them. The manipulation should be confined as much as possible to the scar tissue found upon the ends of the segment.

The work of Stoffel, which has been questioned of late, would seem to indicate that funiculi in peripheral nerves have a definite arrangement. It has been claimed by him that a certain funiculus carries sensory fibers, that another carries motor fibers to a certain group of muscles, etc. He has insisted, therefore, that in performing nerve suture one should be certain that the segments are not rotated during dissection or suture. Whether Stoffel's work is correct or not, the principle which he has insisted upon is important, for there should be as accurate anatomic repair as possible. In secondary nerve suture it is often difficult to determine to what extent rotation has occurred as the result of the traumatizing force. When the nerve ends are dissected out of the bed of scar tissue, silk sutures may be inserted at corresponding points on each segment of the nerve, so that the relative positions may be maintained. A small mosquito forceps placed upon the epineurium at corresponding points will answer the same purpose and prevent rotation.

The next step in secondary nerve suture is resection of the neuroma and scar tissue. A sharp instrument should be used for this purpose so that the nerve will not be contused. A Gillette safety razor blade grasped by an artery forceps may be used for this purpose. Thin slices are removed from the ends of the nerve until healthy neurofibrillæ or funiculi herniate from the cut ends of the segments. Resection of the ends should be carried so far that there is little or no scar tissue in the ends of the nerve which are to be sutured. It has been advised lately that nerve ends be united by the neuroma, and that resection of the ends should not be carried so far as has been advocated. Neurofibrillæ undoubtedly do penetrate scar tissue and seek the distal segment of a nerve. I believe it bad teaching, however, to advocate the union by the neuroma. The success of nerve suture depends upon the accurate end-to-end union of nerve ends which are not infiltrated with scar tissue. Scar tissue will prevent successful suture.

It may be impossible to unite the ends of the nerve when the procedure just advocated has been carried out, unless the segments are mobilized or are displaced so as to produce a relative lengthening. For example, in order to make an end-to-end suture of the ulnar nerve, it may be necessary to dissect the nerve out of the canal in which it runs posterior to the internal epicondyle, and to displace it anteriorly. When this is

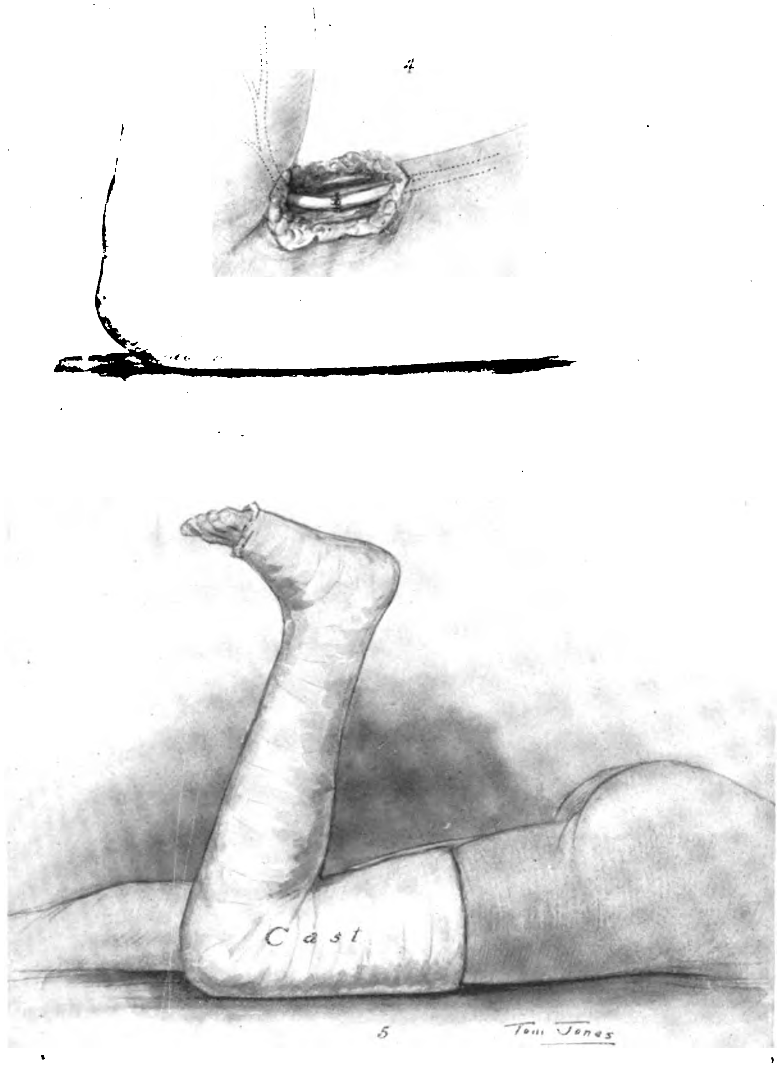

FIG. 229. SUTURE OF SCIATIC NERVE. Approximation of ends secured by mobilizing the segments of the nerve, and flexing the knee to a right angle. Cast fixation should be maintained for six or eight weeks after suture of the sciatic, when end-to-end suture is secured by fixation. In case of the ulnar or median nerve cast fixation is required for about four weeks. (*From the Surgical Clinics of Chicago.*)

done and the forearm is flexed, an end-to-end suture of the nerve is possible, even when the defect measures two inches. In the case of the sciatic, a defect of three inches or more may be overcome by mobilizing both segments of the nerve and flexing the knee to a right angle. Dissection of a nerve out of its normal bed apparently does not interfere with its nutrition and reparative power.

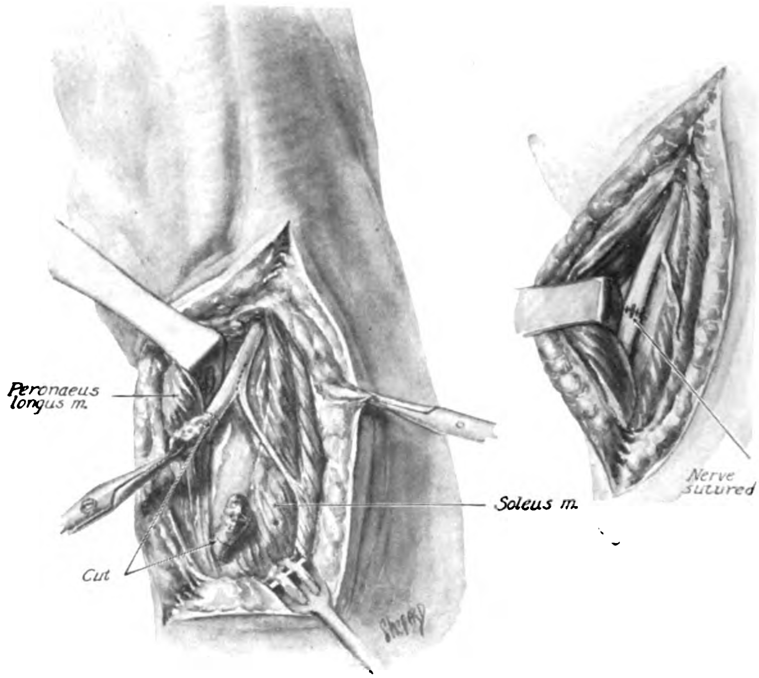

FIG. 230. RESECTION OF NEUROMA. Illustrating extent to which neuroma on the distal end of the proximal segment and scar on proximal end of distal segment are resected in order to expose healthy neurofibrillæ. The ends should be resected until little or no scar tissue is found.

End-to-end suture is desired in all cases, and an attempt should always be made to secure this by mobilization of the segments and by position.

Fine silk or No. 000 chromic catgut may be used in suturing a nerve. Small round intestinal needles, straight or curved, depending upon the exigencies of the case, may be used. Gentle manipulation, a small fine-toothed forceps being used for grasping the nerve, is absolutely essential.

One or two transfixion sutures, depending upon the size of the nerve, should be inserted first. Two will usually suffice, even in the larger nerves, *e.g.*, the sciatic. These should be introduced not less than half an inch away from the cut end. While these sutures are being inserted and tied, the limb should be placed in the position in which it will be fixed when the operation is completed. The coaptation sutures are next applied through the epineurium. These sutures may be interrupted or continuous. When interrupted, enough should be inserted to close the epineurium, in order to prevent the straying into the adjacent tissue of developing neurofibrillæ. These sutures should be applied about the entire circumference of the nerve.

While the type of suture just described is preferred by many surgeons, I believe that four to six sutures which pass through the epineurium will suffice accurately to approximate the ends of the nerves. Fine silk or catgut on fine non-cutting needles may be used for this purpose. The objection which has been raised against this type of suture is that the neurofibrillæ in the center of the nerve ends are not approximated, and that a dead space which fills with blood clot forms. If the epineural sutures are applied correctly accurate approximation can be secured. The results following these two types of suture do not differ.

The suture line when the operation is completed should be placed, when possible, between muscles which have not been injured. It should be protected from scar tissue formation. If the scar tissue in the wound is dense and extensive, it may be advisable to wrap the suture line with fat or Cargile membrane.

In cases in which there has been an actual destruction of the nerve, and the loss has been so great that an end-to-end union cannot be secured by any of the methods previously described, some one of the methods described below must be resorted to.

NERVE TRANSPLANTATION

Experimental work would seem to show that spontaneous regeneration can occur across a gap without artificial aid, provided the distance between the divided ends does not exceed three-fourths of an inch in length. Spontaneous regeneration with bridging of defects does undoubtedly occur in animals. It is doubtful whether it ever takes place in man, although some cases have been reported in which it has apparently occurred. When, therefore, a gap exists in a nerve, some attempt should be made to unite the ends artificially, for this furnishes the only chance of anatomic repair and re-establishment of physiologic function.

The operation of choice in the repair of a defect in a nerve is the autocable transplant, the possibilities of which have recently been shown by the experimental work of Huber.

In making this transplant some cutaneous nerve which may be spared is used. In the upper extremity the internal cutaneous, the superficial branch of the radial, or the external cutaneous is employed. In repairing a defect in the nerve it is best to use three or four parts of the nerve which has been removed, to form the cable. These are sutured to the ends of the nerve by epineural sutures of fine silk. Such transplants are evidently capable of enlargement or growth and may carry

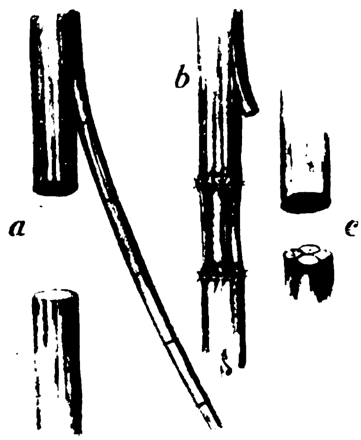

FIG. 231. USE OF THE AUTOCABLE TRANSPLANT. Repair of a gap in the external popliteal nerve.

down enough neurofibrillæ to neurotize the distal segment. Autotransplants are to be preferred in this operation. Homotransplants experimentally serve the purpose. Heterotransplants should not be employed, for they die and form a block against developing neurofibrillæ. In dogs, when a heterotransplant is employed, the developing neurofibrillæ will grow down on the outside of the transplant to reach the distal end of the nerve.

In such cases the French have used rather extensively a method of repair which was advised by Nageotte. This method consists of inserting into the gap a section of a fœtal calf's sciatic nerve preserved and hardened in·50 per cent alcohol. Those who have used this method speak of it very enthusiastically. No reports, however, have been published which would justify this enthusiasm. Experimentally pieces of a nerve preserved in sterile vaseline or liquid petrolatum will serve as a scaffolding to carry developing neurofibrillæ from the proximal to the distal segment. The results obtained in experimental work cannot apparently always be applied directly to clinical surgery, for while in experimental work it is often impossible to prevent a nerve from growing, in clinical

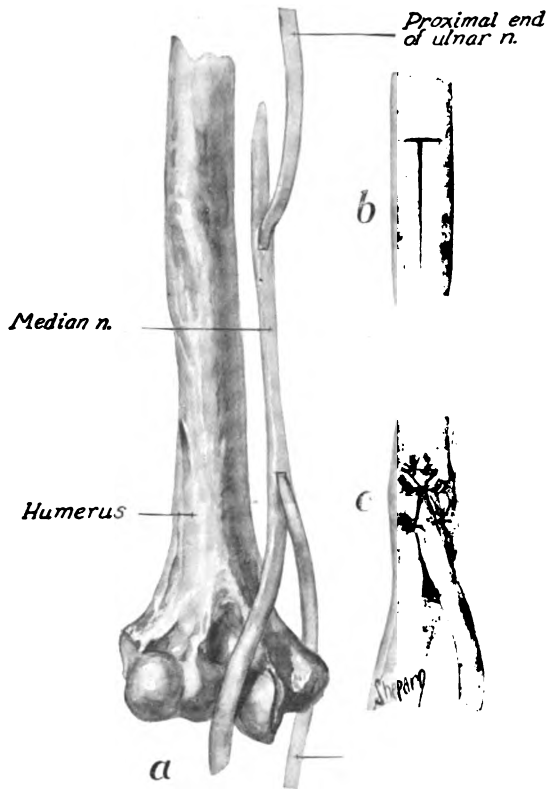

FIG. 232. METHOD OF NERVE GRAFTING. This practically amounts to the use of an autotransplant, the transplant not being raised from its bed.

surgery it is sometimes impossible to secure regeneration or a re-establishment of function, when the principles determined by experimental work have been carefully followed out.

Flap operations, such as the one described by Létievant, should be discarded, for experimental work would seem to indicate that repair of the gap does not occur when this method is employed, and there are not enough successes reported to justify its use.

NERVE GRAFTING

When the gap cannot be bridged successfully, nerve grafting may be resorted to. The results are uncertain. In the arm and forearm the upper end of the divided ulnar nerve may be transplanted into the side of

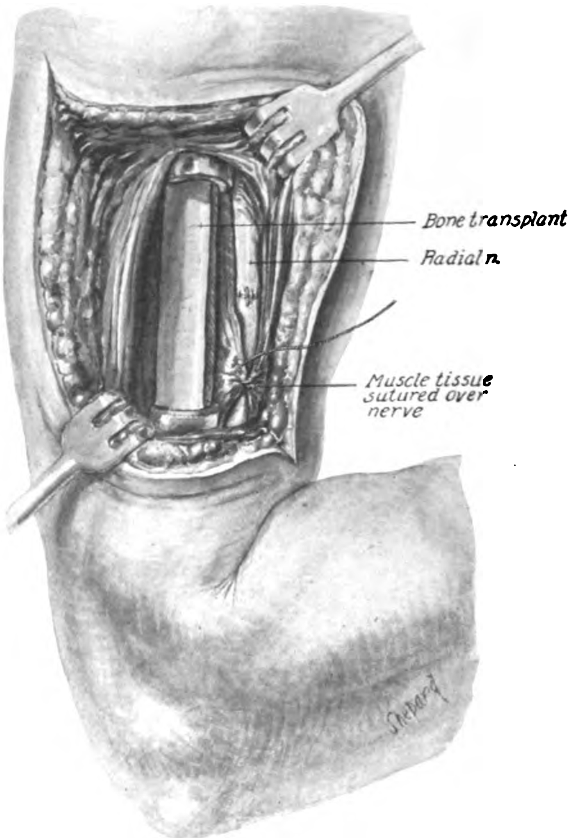

FIG 233. COMBINATION OF BONE GRAFTING AND NERVE SUTURE. In order to secure an end-to-end union of the musculospiral nerve in this case, it was necessary to displace the nerve to the inner side of the arm.

the median, and the distal end of the ulnar may be grafted in the corresponding part of the median at a lower level, an attempt being made to tap the funiculus with which the lower end of the upper segment was placed in contact. This operation is practically an autotransplantation, the transplant not being raised from its bed. Whenever possible, the sensory funiculi in a nerve should be used for conducting the fibers from the injured nerve. When sensory funiculi cannot be used for this purpose, funiculi which supply muscles which can be sacrificed without causing much disability should be used. Extensive multiple nerve grafting has been advocated by some, notably Hofmeister, but the final results evidently do not justify the enthusiasm of the early reports. The autocable transplant is to be preferred to nerve grafting. The results which have been obtained in anastomosis of the paralyzed facial with the hypoglossal or spinal accessory indicate, however, the possibilities of nerve grafting when carefully performed.

TUBULIZATION

Experimentally, nerve fibers will bridge a gap when a tube is formed down which the regenerating neurofibrillæ can grow. Decalcified bone tubules, a segment of a vein or artery, fascia, and a number of other materials have been used to connect the two ends of the nerve, and form a tube to guide the developing neurofibrillæ. While complete regeneration of a nerve, even to the formation of a myelin sheath, occurs in animals after tubulization, there are not enough favorable results reported in clinical surgery to justify an extensive use. It should only be employed as a last resort when other methods cannot be used. A fascial tube may be constructed for this purpose, or a vein which has been turned inside out, so that no endothelium comes in contact with the coagulum which fills the tube. The endothelium of the vein may proliferate and block the lumen if it comes in contact with the coagulum. The use of fascia for this purpose is somewhat limited, for, as previously stated, fascia in contact with a scar is likely to be invaded by scar tissue and undergo contraction.

Resection of a bone or bones of an extremity, with the view of producing a relative lengthening of the nerve, should be discouraged. It has been used to some extent in France in the treatment of peripheral nerve injuries associated with a defect. It should be remembered in this connection that the resection may increase a disability. This may outweigh the advantages secured by a successful suture.

SURGICAL TREATMENT OF PAINFUL LESIONS—CAUSALGIA

Causalgia was described by Weir Mitchell. It was observed by him in the wounded under his care during the Civil War. It is observed most frequently after gunshot wounds involving the median and internal

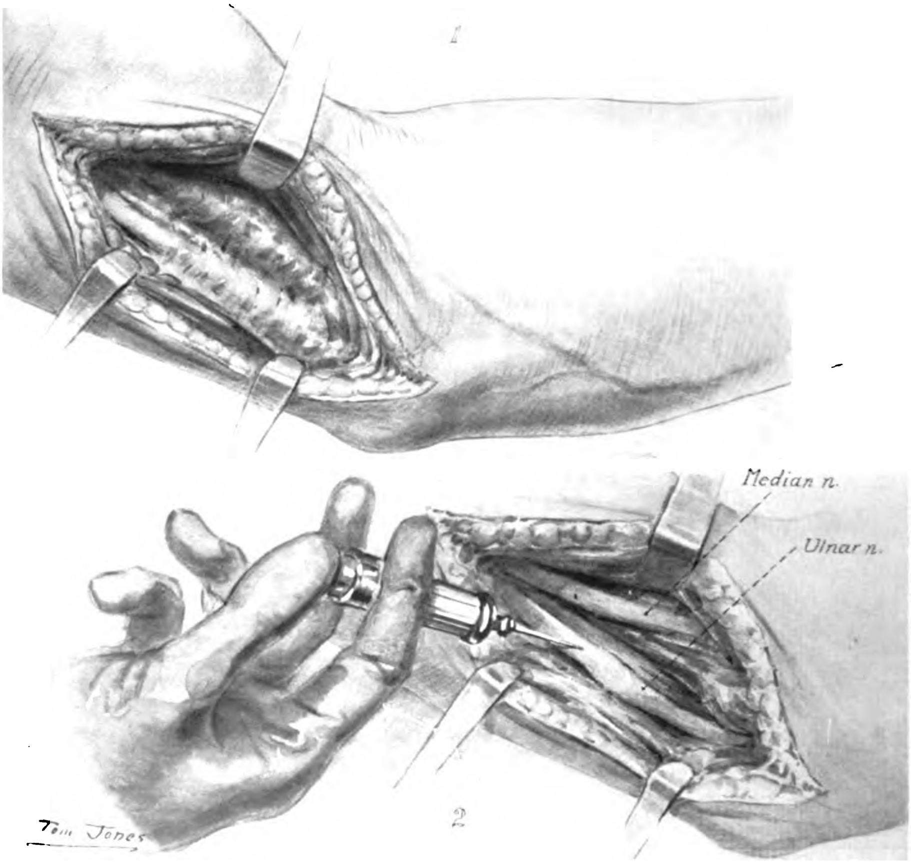

FIG. 234. PATHOLOGIC CHANGE IN A CASE OF CAUSALGIA. Liberation of the ulnar and median nerves with injection of the median nerve with 60 per cent alcohol, followed by almost immediate relief. (*From the Surgical Clinics of Chicago.*)

popliteal nerves. In some instances the pain has been controlled or benefited by neurolysis, the nerve having been bound down in a scar. Often the pain returns after liberation. Injection of the nerve above the point of injury with 60 per cent alcohol gives almost immediate relief in most of these cases. The ulcers and excoriations which are so often found in causalgias, the result of maceration or scratching, heal rapidly. Alcohol injection is a simple procedure which gives brilliant results and is to be preferred to the peri-arterial sympathectomy which has been advised by Leriche in this class of cases.

POSTOPERATIVE TREATMENT OF PERIPHERAL NERVE LESIONS

When peripheral nerves have been divided, recovery of function of the muscles supplied by them takes place slowly, even when a primary suture has been performed, and all the principles governing neurosurgery have been complied with. I have seen return of motor function in two cases of suture of the divided musculospiral nerve in five and one-half months. This is the shortest length of time after suture that I have noticed return of function.

The paralyzed muscles should receive careful attention after a nerve is divided, and during the period of repair following operation. The extremity should not be allowed to hang loose, for the paralyzed muscles should not be stretched. Overstretching of the fibers prevents or interferes with the return of tone and prolongs the disability. When emphasizing the necessity of keeping paralyzed muscles in a relaxed or neutral position, it is only fair to say that of late too much emphasis has been laid upon the necessity of splinting, even in an overcorrected position, with a view of securing complete relaxation of the paralyzed muscles. Too assiduous, rigid splinting is often followed by ankylosis of the joints, and marked atrophy of the group of muscles involved. In the cases which we have recently seen, it has seemed as if the amount of atrophy were almost directly proportional to the care and assiduity with which the splinting had been done.

During the after-treatment of these cases there should be the closest co-operation between the surgeon, neurologist, and physiotherapist. Each case should be studied repeatedly, and a prescription should be given for treatment, depending upon the conditions found at the time the examination is made.

Rigid splints should not be used for purposes of fixation when they can be avoided. The glove splint with elastic extension at the wrist is preferable to the rigid splint in the treatment of musculospiral palsies.

The wire splint used in the treatment of external popliteal palsies has enough spring to permit of some play of the muscles.

Fibrosis of the joints, especially of the metacarpo-phalangeal and interphalangeal in the hand, must be carefully guarded against in ulnar and median nerve lesions. It may have to be overcome by special appliances.

Sir Robert Jones, in particular, has pointed out the fundamental importance of maintaining nutrition of the muscles and integrity of the joints during the period of treatment preliminary to operation. The impossibility of expecting a return of function after nerve suture when the muscles have been kept under prolonged tension from the unopposed action of healthy muscles, or have been allowed to undergo atrophy, or when a fibrous ankylosis of the joints has taken place, admits of no argument.

Treatment by massage, by alternating hot and cold baths, by electrical stimulation when nerve regeneration has begun, by exercises, passive and active, as soon as the condition of the limb will permit, are all of importance in securing a complete return of function. (This subject is discussed more fully in Section IX, Volume I.)

Ultimate success in peripheral nerve surgery is dependent upon careful dissection, without injury or contusion of the nerve; asepsis; the control of hæmorrhage; perfect anatomic repair, with an accurate end-to-end approximation of the nerve trunks or transplants when possible; and, finally, patient and persistent after-treatment.

It cannot be definitely stated when return of motion will begin after suture. As stated above, I have noted return of motion in the muscles supplied by the musculospiral nerve as early as five and one-half months after suture. It is probable that the greatest number of recoveries occur from the ninth to the twelfth month. The musculospiral nerve recovers earliest after suture, then the internal popliteal, the median, and the ulnar. The external popliteal, after both high and low suture, recovers more slowly than the nerves mentioned above.

Recovery of function is manifested in different ways. In some cases the first evidence of successful suture is the ability to use the paralyzed muscles, the return of power being manifested suddenly. In one case which I observed, there was no consciousness of return of power until the patient was asked to extend his wrist, when he found that he could do so. Rapid recovery of motion then occurred. In other instances, marked hyperæsthesia of the skin supplied by the sutured nerve precedes or accompanies return of motion.

In determining the return of motor power, one should always remember that certain movements, the loss of which is supposed to follow particular nerve lesions, may be preserved. Superficial study and wrong interpretation of supplementary muscle movements probably account for some of the reports of very early return of motion after nerve suture. These supplementary movements, according to Pollock, may be caused by a number of factors. Among these may be included the anastomotic supply of muscles from adjacent nerves; movements produced by muscles other than those primarily producing this action; movements occurring as the result of mechanical factors producing a change of direction of leverage by shortening and lengthening of tendons and muscles passing over several joints; and slight movements resulting from the recoil of elastic tissue following a movement in a direction opposite to the one desired. These movements should be carefully observed when studying the return of power.

Epicritic sensation returns late. Muscle power may have been almost fully recovered when there is still no evidence of the return of epicritic sense.

CHAPTER II

OPERATIONS UPON THE CRANIAL NERVES AND THE GASSERIAN GANGLION

EXPOSURE OF THE SUPRA-ORBITAL NERVE

Indications. This nerve, which is the largest of the terminal branches of the ophthalmic division of the fifth nerve, is exposed either for the purpose of stretching it, or, preferably, of resecting a portion in those cases of trigeminal neuralgia in which the pain is limited to the first division.

Surgical anatomy. The nerve leaves the orbit through the supra-orbital notch, and ascends vertically over the frontal bone to supply the adjacent portion of the scalp. The supra-orbital notch is situated at the junction of the middle with the inner third of the upper margin of the orbit, and in this situation the nerve lies beneath the fibres of the orbicularis palpebrarum (oculi) muscle, and divides into two or more branches almost immediately after it has emerged from the notch. The supra-orbital vessels are on its outer side and not so deeply situated.

Operation. The eyebrow need not be shaved; it suffices to purify it thoroughly. Irregular growth of the eyebrow may follow shaving, which experience has proved to be unnecessary. The surgeon defines the supra-orbital notch and makes a curved incision about half an inch long, following the upper margin of the orbit with its centre opposite the notch. The fibres of the orbicularis palpebrarum (oculi) are separated with the handle of the knife until the periosteum is reached, when the notch can be felt and the nerve seen emerging from it close down on the periosteum. In order to stretch the nerve a hook is passed beneath it; should it be desirable to remove a portion, the nerve is pulled up with a hook, divided some little distance up on the scalp, and then as much of the nerve as possible is pulled out by grasping the proximal cut end in Spencer Wells's forceps and winding the nerve around the blades so as to tear away as much as will come. The incision above recommended leaves very little scar, as it is made through the eyebrow; as it is parallel to the fibres of the orbicularis these do not gape when the wound is closed.

RESECTION OF THE SUPERIOR MAXILLARY NERVE

Indications. This nerve is frequently resected for obstinate trigeminal neuralgia affecting chiefly the second division. It is never exposed merely for the purpose of being stretched. The operation usually gives relief for a period varying from a few weeks to two years or longer, but rarely succeeds in effecting a permanent cure.

Surgical anatomy. This nerve, the second division of the fifth, is about two inches in length, and extends from the foramen rotundum to the infra-orbital foramen on the front of the superior maxilla, where it breaks up into its terminal branches.

The infra-orbital foramen is localized by drawing a line from the supra-orbital notch to the interval between the two lower bicuspid teeth. Along this line lies the infra-orbital foramen about half an inch below the lower margin of the orbit. In the spheno-maxillary (pterygo-palatine) fossa between the foramen rotundum and the back of the upper jaw lies Meckel's (spheno-palatine) ganglion, which should be removed with the nerve; in order to get beyond all the branches of this division the nerve should be divided on the proximal side of the ganglion. In its course through the upper jaw the nerve lies partly in the infra-orbital canal.

Operation. The nerve may be resected:

(i) At the infra-orbital foramen.

(ii) Behind Meckel's (spheno-palatine) ganglion at the foramen rotundum. This operation is much more satisfactory in its results than the former, although it is far more difficult to perform.

At the infra-orbital foramen. The head is turned slightly towards the affected side and is raised upon a pillow, the position of the infra-orbital foramen is determined (*vide supra*), and a slightly curved incision about half an inch in length with its concavity upwards is made so that its centre crosses the foramen. This incision exposes the fibres of the orbicularis palpebrarum (oculi), which are separated in the line of the incision, and those of the levator labii superioris (caput infra-orbitale) are then exposed and split in the direction of their fibres. This exposes the trunk of the nerve, which divides into a number of branches as it emerges from the foramen. There is often troublesome bleeding due to damage to the infra-orbital artery or vein, and it may be necessary to employ adrenalin in order to stop this. The nerve is picked up with a blunt hook as it emerges from the foramen, divided with scissors about half an inch from it, and the proximal end is seized in Spencer Wells's forceps and twisted around the blades so as to drag as much of it out of the foramen as possible.

This operation is not followed by much success and is therefore rarely performed.

At the foramen rotundum. In order to remove the nerve as far back as the foramen rotundum it must be followed up through the upper jaw. The incision most frequently advised is a V-shaped one, the apex of the V being downwards and its centre just below the infra-orbital foramen. A less noticeable cicatrix may be obtained by planning the incision so that it lies in one of the natural folds of the face. I have found the one recommended by Kocher to be the easiest to work through and the best as far as the æsthetic result is concerned. It commences just below the inner end of the infra-orbital margin, and runs obliquely downwards and outwards to the lower angle of the malar bone. It should be sufficiently long to give good exposure of the anterior surface of the superior maxilla from the canine fossa to the lower margin of the orbit.

After having made the skin incision, the surgeon separates the fibres of the levator labii superioris (caput infra-orbitale) and finds the infra-orbital nerve as it comes out of the foramen (*vide supra*), and fastens a ligature to it in order to identify it during the rest of the operation. The nerve is then cut through on the distal side of the ligature.

The front of the jaw is cleared of muscles and periosteum and is cut away with a chisel so as to leave a square hole, the sides of which are an inch long. This should be so planned that the infra-orbital foramen is slightly below the centre of the square, the upper edge of which will be just below the margin of the orbit. In doing this care must be taken not to tear the nerve, which is left hanging out through the opening. As the antrum is opened up there is usually free oozing, which may be stopped by packing the wound with small pledgets of wool dipped in adrenalin chloride (1 in 1,000); adrenalin is most useful in this operation, and it is almost impossible to get a clear view without it. When the bleeding has ceased, the surgeon, with the aid of a forehead-light, identifies the nerve hanging from its bony canal in the roof of the antrum, and clips away the lower wall of this canal with scissors or a very fine chisel. The nerve must not be damaged in doing this or else the guide to the subsequent steps of the operation will be lost.

When the whole of the bony floor of the canal in which the nerve lies has been cut away right to the back of the posterior wall of the antrum, an aperture, similar to but slightly smaller in size than that already made on the anterior wall, is cut out of the posterior wall in a similar manner. This leaves the nerve protruding through the cavity, and, after stopping the bleeding and pulling it taut, it can be traced up to the foramen rotundum and Meckel's (spheno-palatine) ganglion identified. While traction is kept up on the ligature attached to the nerve, a pair of Spencer Wells's forceps is slipped up around the trunk nearly to the foramen rotundum and the nerve is either pulled out forcibly from, or cut off flush with the foramen with a pair of curved scissors; in either case the ganglion will come away with the trunk. The nerve should always be pulled as far out of the foramen as possible, so that it may retract inside it after it has been divided.

RESECTION OF THE INFERIOR MAXILLARY NERVE

Anatomy. The third or inferior maxillary (mandibular) division of the fifth nerve leaves the skull by the foramen ovale, and divides almost immediately into two main branches, the anterior being the smaller and giving off the temporal, masseteric, buccal, and the external pterygoid branches. From the posterior or larger division arise the auriculo-temporal, lingual, and inferior dental (alveolar) branches.

In trigeminal neuralgia the pain may be most marked in, or entirely confined to, this division of the fifth nerve, and under these circumstances it is usual to try the effect of division of its terminal branches in the first instance. Should this fail, it has been recommended to divide the main trunk at its exit from the foramen ovale, but, having regard to the want of success of the operation as regards recurrence of pain, and looking also at the severity of the operative procedure and the disfigurement it entails, it would seem better to expose and remove the Gasserian ganglion in all cases of neuralgia of the third division in which neurectomy of the inferior dental (alveolar) or lingual branches has proved ineffectual.

Resection of the inferior dental nerve. **Indications.** (i) Persistent neuralgia. This operation will be practised when the neuralgia is comparatively recent and is limited to the distribution of the inferior dental nerve, or to it and the lingual branch, in which case the latter nerve will be divided at the same time (see p. 588).

(ii) Certain cases of inoperable cancer of the tongue or jaw in which the pain is excessive and cannot be subdued by narcotics. Simultaneous resection of the lingual nerve (see p. 588) will be probably required here also.

Operation. The patient's head is well propped up and the mouth is opened widely with a gag; the table must be so arranged that a good natural or reflected light is directed upon the affected side. The surgeon stands on the opposite side, and the tongue is pulled to that side and kept well out of the way by a suitable broad tongue depressor. As it is essential that the tongue should not slip and obscure the view, a stout silk ligature passed well through its centre may be used as a retractor, or sharp-pointed single tenaculum forceps may be used.

An incision about one inch long is made parallel with, and just internal or posterior to, the anterior border of the ascending ramus of the jaw, and the muco-periosteum is separated from the bone until the inferior dental (mandibular) spine is felt above the commencement of the inferior dental (mandibular) canal. The long internal lateral (spheno-mandibular) ligament of the jaw, which is attached to the spine, is carefully divided with fine blunt-pointed scissors, and then the inferior dental (alveolar) nerve is identified just behind this and hooked up into the wound. There is free oozing during this stage of the operation, and it may be advisable to have recourse to temporary plugging with adrenalin chloride (1 in 1,000). The nerve lies in front of the inferior dental (alveolar) vessels, but it is close to them as it enters the canal, and they may be easily wounded by careless manipulation. Half an inch or more of the nerve is removed with scissors, and the wound is left to heal by granulation.

The mouth is washed out frequently with a mouth-wash containing one drachm of sanitas to the pint. The patient is generally well in a week; there is stiffness and pain in the jaw for the first few days only.

This operation is much to be preferred to the method of reaching the nerve through the outside of the cheek by exposing and deepening the sigmoid (mandibular) notch of the lower jaw. The latter method is easy, but it leaves an unsightly scar and therefore will not be described; the intra-buccal method described above, although rather difficult owing to the free venous oozing, is nevertheless to be preferred.

Resection of the lingual nerve. **Indications.** As for the preceding operation (see p. 587).

Operation. The patient is propped well up, the head is turned to the opposite side, and the mouth is opened widely, while the tip of the tongue is grasped in forceps and pulled firmly to the opposite side. The nerve at once stands out in relief beneath the mucous membrane of the tongue behind the last lower molar tooth. An incision about half an inch long is made parallel to and just over the nerve, which is caught up with a blunt hook and the desired portion excised. No sutures are needed to close the wound in the mucous membrane.

Resection of the auriculo-temporal nerve. **Indications.** This operation is hardly likely to be called for in the living subject. Pain in the auriculo-temporal nerve in cases of trigeminal neuralgia will usually call for more radical measures, such as removal of the Gasserian ganglion. When pain in this nerve occurs in connexion with cancer of the tongue or jaw the pain is reflex, and may be stopped by division of the lingual or inferior dental (mandibular) nerves or both.

Operation. The nerve can be exposed by a vertical incision over the posterior root of the zygoma midway between the tragus and the condyle of the jaw. The incision need only be half an inch in length, and the nerve will be found posterior to and parallel with the superficial temporal artery (see Fig. 218).

REMOVAL OF THE GASSERIAN GANGLION

Indications. Removal of the Gasserian (semilunar) ganglion is the only reliable cure for inveterate trigeminal neuralgia that has resisted prolonged medical treatment and has recurred after any of the preceding operations upon the branches of the fifth nerve have failed to give permanent relief. The operation is one of considerable severity, and the mortality directly traceable to it is still comparatively high; therefore it should not be resorted to until it is clear that other methods have proved ineffectual. At the present time most surgeons perform resection of some of the terminal branches of the fifth, such as the infraorbital, lingual, or inferior dental (alveolar) nerves, before proceeding to remove the ganglion, because the period of freedom from pain following these milder operations is often considerable. On the other hand it is important that the operation should not be delayed until the patient is broken down in health by the excessive pain, want of sleep, and, possibly, abuse of morphine.

Surgical anatomy. The Gasserian (semilunar) ganglion is reniform in shape with its convexity directed forwards and outwards. It rests in a special depression upon the upper surface of the petrous portion of the temporal bone and the cartilage filling up the foramen lacerum medium. It is of a reddish grey colour and lies in a cleft in the dura mater (Meckel's cave). From its anterior border are given off three main divisions, the first or ophthalmic being long and slender and running horizontally forwards, whilst the third or mandibular division is short and stout and passes almost vertically down from the ganglion to the foramen ovale so that very little of it is seen in the field of operation. The middle or (superior) maxillary division is longer and is intermediate in size between the other two; it passes forwards and a little downwards to the foramen rotundum. Both the ophthalmic and the (superior) maxillary divisions lie in close relation to the outer wall of the cavernous sinus, particularly the former, which lies a little below and parallel to the fourth nerve until the latter's disappearance into the orbit through the sphenoidal (superior orbital) fissure. The inferior maxillary (mandibular) branch receives the small motor root of the trigeminal nerve, which passes forward beneath the ganglion; beyond the foramen ovale they join together to form the inferior maxillary (mandibular) branch. The point at which the trigeminal nerve expands into the ganglion is within the dura mater, which here forms a sheath of investment around it. The ganglion itself, or at any rate the greater portion of it, and its main divisions lie outside the dura mater.

Operation. A number of methods have been employed for the exposure and removal of this structure. The one first described was by an extra-dural route through the foramen ovale, and was introduced by Professor Rose, who was the first surgeon to remove the ganglion (*Lancet,* November 1, 1890). This method, however, has fallen entirely into disuse owing to the difficulty, danger, and uncertainty attending it. It is certain that in very few cases was the ganglion reached and entirely removed by this method.

The next operation in chronological order is that of Sir Victor Horsley, who opened the skull from the temporal region, divided the dura mater, lifted up the temporo-sphenoidal lobe, and removed the ganglion from within the dura mater. The patient died of shock, and the operation did not become popular. Its place was soon taken by the method now known as the Hartley-Krause method, which was described independently by Dr. Hartley (*New York Medical Journal,* vol. lv, 1892) and Professor Krause (*Deutsche Med. Wochenschrift,* 1893, No. 15), the details of which are given on p. 600. It will be seen that this method consists essentially in making a large opening in the temporal region, either with or without an osteoplastic flap, and then raising the dura mater from the floor of the middle fossa of the base of the skull until the ganglion is reached and can be removed.

This method held the field for a considerable time to the exclusion of all others, and is even now the operation most generally practised. While it may well be granted that this method is a great improvement upon its predecessors, it will probably have occurred to most of those who have performed it that the opening in the skull is placed too high up, and that the difficulties of the operation are greatly increased by having to raise the brain inside the dura mater for a considerable distance out of the floor of the middle fossa before the ganglion can be reached. Examination of the skull will show that if the opening be made lower down, the operation can be done with much less interference to these important structures, and in my last four cases I have abandoned the Hartley-Krause method in favour of a modification of the method introduced by Cushing and described by Kocher (*Operative Surgery,* translated by H. J. Stiles, 2nd ed., 1903).

The modified Cushing method. The operation that I use is a compromise between that of Cushing, who peels down the temporal muscle, and therefore restricts the field of operation, and that of Doyen, who, after sawing through the zygoma as Cushing does, divides the attachment of the temporal muscle to the coronoid process and turns it and its tendon upwards, thus giving a clear space above the pterygoid ridge where space is of most value. In Doyen's operation a trephine opening is made immediately above the pterygoid ridge and, after the inferior maxillary (mandibular) nerve has been identified as it leaves the foramen ovale, the base of the skull is chiselled away between the trephine opening and the outer margin of the foramen ovale. In this way it is possible to get at and remove the ganglion without disturbing the dura mater, and therefore without exerting injurious pressure upon the brain above.

I am inclined to think that the methods of both Doyen and Cushing are superior to the Hartley-Krause; of the two I prefer that of Cushing modified in the manner to be described immediately, as the removal of the thick base of the skull in Doyen's method gives rise to bleeding, which is not only exceedingly troublesome, but may be actually dangerous.

The modified Cushing method will be described first in full; subsequently the chief steps of the other operations will be indicated briefly.

Operation. Shock must be guarded against most carefully, as the operation is sure to be prolonged under the most favourable circumstances; if the operator be inexperienced it is no uncommon thing for it to last more than two hours. Moreover, the patient is generally elderly and broken down in health, and the bleeding is always free. The operating room should be at a temperature of at least 70° F., the patient should be warmly wrapped up upon a hot-water table, and should have a nutrient enema containing 1 oz. of brandy before operation. The apparatus for saline intra-venous infusion should be at hand. The surgeon must be provided with a powerful electric forehead-lamp, without which it is impossible to get a good view of the depths of the wound; the lamp, properly focused, should be fitted on before the operation is begun, so that an assistant can switch on the light during the operation and the surgeon need not touch the lamp himself. Horsley's aseptic wax [1] and adrenalin chloride should be at hand.

The patient should be propped up as much as the anæsthetist will allow, in order to minimize the venous oozing which is invariably a serious hindrance during the operation, and the head should be thrown

[1] Beeswax 7 parts, almond oil 1 part, and salicylic acid 1 part. This is mixed and sterilized by immersion in boiling water, and is kept under 1 in 20 carbolic solution. It is a hardish wax that must be softened by working it up in the fingers.

somewhat back and turned slightly to the opposite side; a special head-rest attached to the table very greatly facilitates matters. A most important point is to see that the anæsthetist and his apparatus do not trespass upon the field of operation. The operation is a long one, and there must always be a risk of septic infection owing to the proximity of the wound to various sources of contamination.

After numerous trials I have found that the best way of securing this object is to fasten one edge of a sterilized towel to the skin all around the proposed area of operation by means either of sutures or special forceps, which clip the skin to the towel. The other edge of the towel is then hung over a suitable rest, so that it serves as a curtain which cuts the anæsthetist off from the field of operation. This plan is much more satisfactory than the method of laying cloths around the operation area and encircling the head with them. It is impossible to prevent the towels from becoming displaced unless they are actually fastened to the skin, and in this particular operation even a slight displacement may open the door to septic contamination, which has had such serious results in the past. Another not inconsiderable advantage of securing the cloths to the skin in this manner is that a much smaller area of the scalp need be shaved and purified. It used to be the custom to shave at least half of the scalp, and in many cases the whole of the hair-bearing area was shaved and purified. This is a very serious drawback, especially in women, and experience shows that it is not necessary. If the sterilized cloths be secured around the operation area in the manner recommended, it is sufficient to shave the hair for the space of a clear inch and a half around the incision in all directions, and if the cloths be fastened to the edge of this space it is impossible for contamination from the hair to occur, while the plan has the great advantage that after recovery the area of operation is comparatively easily hidden by dressing the hair over it. I have adopted this plan in these cases for the last two years, and have also employed it in operations upon the mastoid antrum, in which preservation of as much of the hair as possible is a point that appeals very strongly to the patient. I have found that the incision can be carried into close proximity with the hairy scalp without any risk of infection.

The temporal region is purified by means of the usual compress applied overnight, and by thorough purification immediately before the operation. It is important to protect the conjunctiva on the affected side, and this is best done by suturing the eyelids together. The conjunctiva and the conjunctival sac are first washed out with warm boric lotion (gr. v ad ℥i), and the lids are then stitched together by pinching up a fold of each and fastening them with a running stitch of fine silkworm-gut. This suture is left in place for a few days after the operation (see p. 599).

The incision generally used is omega-shaped (see Fig. 242); this gives a good exposure if it be carried down to the level of the zygoma. This, however, entails division of the nerve-supply to the orbicularis, and therefore for the last two years I have substituted the sickle-shaped incision (Fig. 235), which avoids the branches of the facial nerve. This

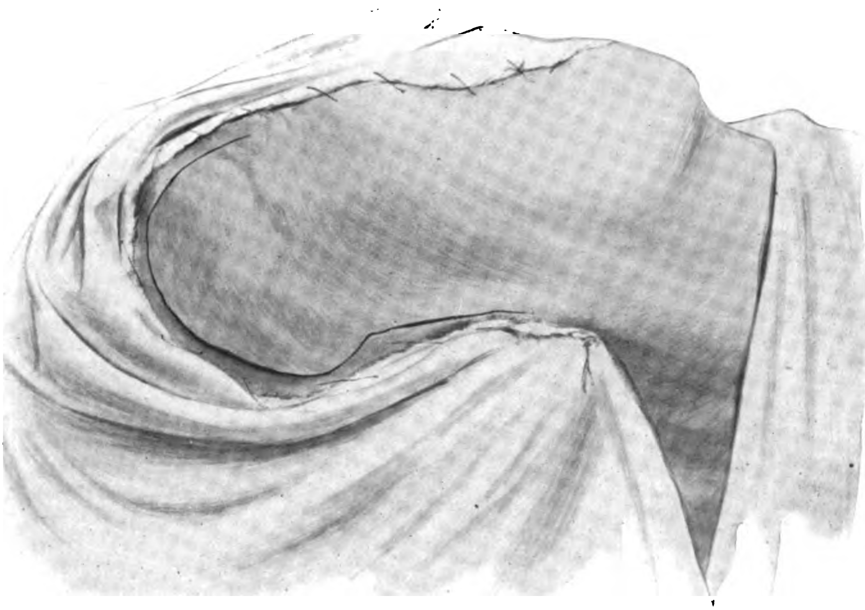

FIG. 235. INCISION FOR REMOVAL OF THE GASSERIAN GANGLION. The drawing shows the sterilized cloth sewn to the skin. In the actual operation the free edge of this is hung over a special screen.

incision commences well below the zygoma just in front of the superficial temporal artery, and runs vertically up for about an inch and a half; it then takes a bold curve with its concavity forwards, extending up as far as the outer angle of the orbit. This is practically identical with the later incision recommended by Cushing (*Annals of Surgery*, 1906, vol. xliii, p. 1). Quite a good exposure is got by dragging the skin flap downwards and forwards over the zygoma. Both these incisions only go down to the deep fascia.

The temporal fascia and the periosteum are divided over the posterior end of the zygoma, and that bone is sawn through or divided with cutting pliers. The temporal fascia is then divided along the upper margin of the bone until its anterior end is exposed. This is divided in a similar manner, and the bone, together with the muscle and fascia attached to it, can then be drawn downwards by a retractor. This brings into view the coronoid process with the tendon of the temporal muscle inserted into it (see Fig. 236). The coronoid process is sawn through, or the temporal tendon is detached from it, whichever seems the more easy to the operator, and, when this has been done, the temporal muscle is turned up so as to expose the lateral surface of the skull just above

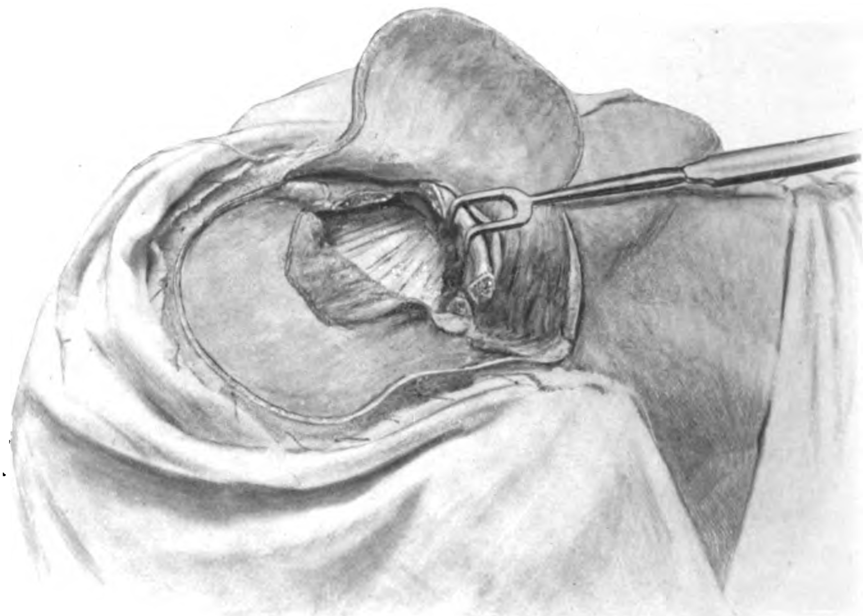

FIG. 236. SECTION OF THE ZYGOMA. The temporal muscle is exposed to view.

the pterygoid ridge. This is the region in which the skull is to be opened, and the opening may be made either with a one-inch trephine or with a gouge. The former method is the more rapid, the latter perhaps the safer, but in any case the bone must be cut through very cautiously owing to the varying thickness of the skull. Much inconvenience will be caused to the operator should the dura mater be inadvertently opened at this stage of the operation.

When the opening in the skull has been made it must be enlarged in all directions with suitable bone-cutting forceps, preferably as much downwards as possible, so as to make the opening in the bone nearly on a level with the floor of the middle fossa of the base of the skull. An opening two and a half inches from front to back and two inches from above downwards ought to give enough room for the subsequent manipulations (see Fig. 237). During this stage of the operation, very troublesome bleeding from the bone and the pterygoid plexus is nearly always encountered. Bleeding from the bone can be stopped by pressing Horsley's wax firmly into the bleeding surface if necessary, whilst the venous oozing is best controlled by packing the wound firmly with gauze impregnated with adrenalin chloride (1 in 1,000).

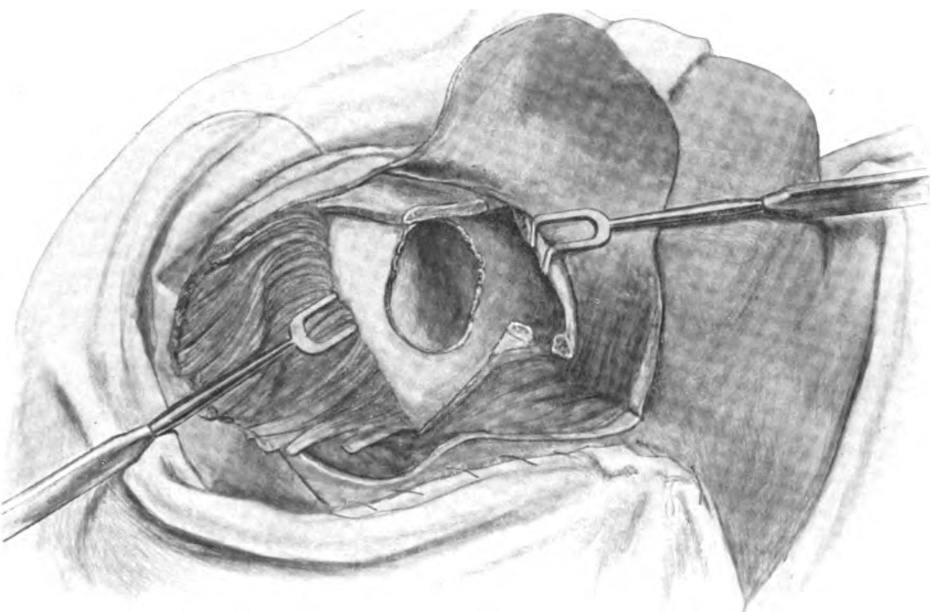

FIG. 237. EXPOSURE OF THE FLOOR OF THE MIDDLE FOSSA OF THE BASE OF THE SKULL. The dura mater is being lifted out of the base of the middle fossa. The temporal muscle has been turned up and the flap protected by gauze.

The next step is to raise the dura mater from the base of the skull, and this should be done at first with a fine instrument like Horsley's dura mater separator, but, as the operation proceeds, the finger should be substituted for it. The dura mater and the superjacent brain are raised gently and slowly so as to mould the brain gradually into its new position and to avoid bruising its under surface. Broad, thin, flexible spatulæ are most useful for holding up the brain, and a number of varying widths should be at hand.

The first structure met with on raising the dura from the floor of the middle fossa will probably be the middle meningeal artery. The vessel enters the skull through the foramen spinosum, which lies behind and to the outer side of the foramen ovale. As a rule, the artery need not be interfered with, but if it gets in the way it will be necessary to secure it. The best way of doing this is to seize and divide it between two pairs of forceps some distance above the foramen; the proximal end is then twisted up several times and, if necessary, pushed down into the foramen with a stout probe. Another plan is to pass a ligature round it by means of an aneurysm needle with a very small curve, or special forceps (see Fig. 238), and tie it just above the foramen. If by mischance the artery should be torn across flush with the foramen, the bleeding from it may be stopped by pushing a probe well into the foramen, or, failing this, by plugging the latter with Horsley's wax.

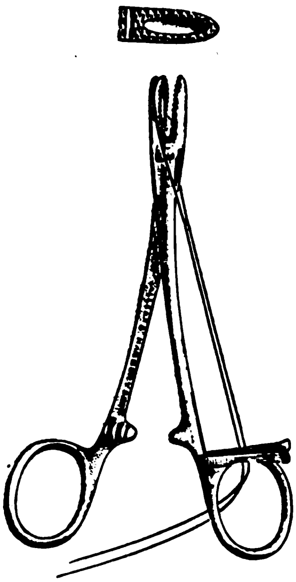

FIG. 238. SCHOEMAKER'S ARTERY FORCEPS. This is an ingenious device for tying deeply seated vessels. The suture is held taut by the clips on the handle, and the forceps are used to pick up the vessel, just as are Spencer Wells's. When the vessel has been seized, the ligature is loosened from the clips and tied.

As the separation of the dura mater proceeds, the three divisions of the nerve come into view; first the third, then the second, and finally the first division are seen (see Fig. 239). The second division is usually the most noticeable, and the third is quite short and may be difficult to identify at first. At this stage of the operation there is usually free oozing, which has to be met by continuous sponging and the use of adrenalin and firm temporary packing.

In order to diminish the risk of arterial bleeding still further, Crile (*Annals of Surgery*, 1906, vol. xliv, p. 842) exposes the common carotid artery and clamps it temporarily by his temporary compressors. In spite of these precautions there will still be serious oozing from the veins and sinuses inside the skull, and to check this he keeps small rolls or pledgets of sterilized gauze pressed firmly round the operation area with special spatulæ, shaped like small tongue depressors. These compress the bleeding points and keep the operation area free of blood; they are shifted from place to place as the operation progresses.

Of the usefulness of this latter precautior. I can speak from experience. With a proper supply of small pledgets and an assistant who understands where to pack them, the later stages of the operation, which are generally the most difficult, are greatly facilitated. I have never had recourse to temporary clamping of the carotid in this operation, as

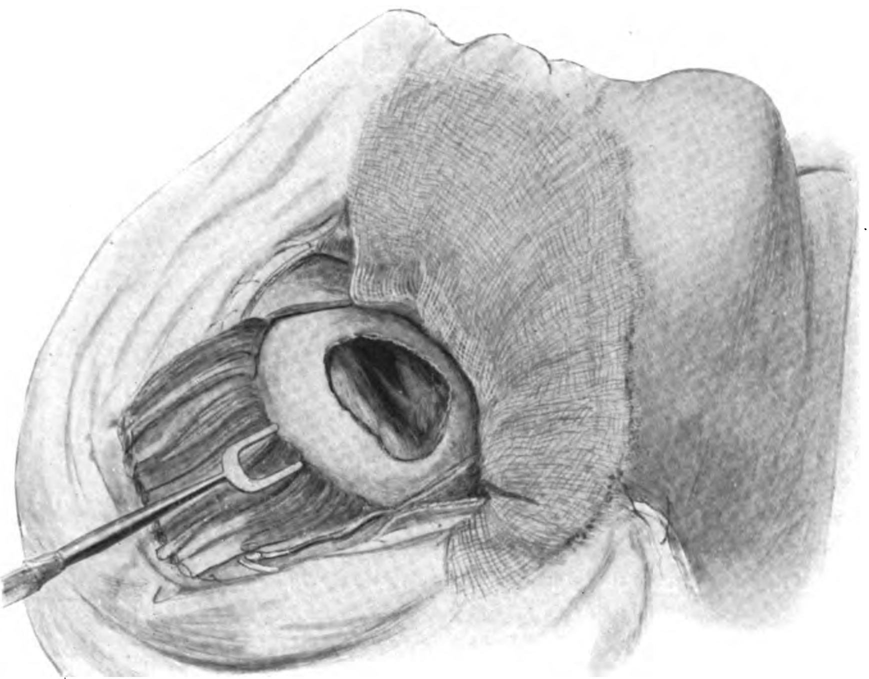

FIG. 239. EXPOSURE OF THE GASSERIAN GANGLION. The ganglion and its three branches are seen lying deep inside the skull.

the arterial bleeding is usually very slight if the superficial temporal be tied at an early stage and care be taken not to injure the middle meningeal when raising the dura mater. When, however, the orthodox Hartley-Krause method is adopted there is often very severe hæmorrhage in turning down the cmega-shaped flap, and it is also easy to damage the middle meningeal artery and difficult to pick it up; under these circumstances temporary compression of the common carotid may be worth the extra time that it entails.

The dura mater is steadily raised from the upper surface of the nerves and the ganglion until they are thoroughly exposed; the dura mater may be punctured at this stage of the operation, in which case the cerebro-spinal fluid escapes and allows it to collapse somewhat. The third division is isolated by means of a fine dissector and is caught up on a fine blunt hook and divided with a blunt-pointed tenotome as close to the foramen ovale as possible. The motor root of the fifth lies behind the main trunk and should be left intact. The divided proximal end of the third division is now caught up in strong long-handled catch forceps and lifted upwards and forwards so as to put the posterior and outer margins of the ganglion upon the stretch. This portion of the periphery of the ganglion is isolated with a fine dissector, and the main trunk of the fifth nerve is cut across well behind the ganglion, which is then pulled forward, separated from the bone beneath, and its first and second divisions gently raised from the wall of the cavernous sinus and divided as far forward as possible. If the motor root of the nerve can be identified when the ganglion is raised from its bed it should be left uninjured, but this is often impossible owing to free oozing from the small tributaries of the sinus.

Some authorities recommend that the ophthalmic division should be left intact whenever the pain in that branch is not pronounced; personally, I am in favour of removing all three branches with the ganglion for fear of recurrence. Should the surgeon decide, however, to leave the ophthalmic division intact, his best plan, after having divided and secured the third division, is to divide the second division at the foramen rotundum and seize it in forceps as he did the third division; in this way the ganglion can be lifted out of its bed and removed by a few snips of a pair of fine blunt-pointed scissors, while the first division is left intact.

The advantage of dividing the nerve behind the ganglion and turning the latter forwards with the second division attached to it is that there is less likely to be serious bleeding from the cavernous sinus, which is easily wounded when the second division is separated from it. Should this accident happen, the operation must be suspended for some minutes while the wound is packed firmly with pieces of sponge or gauze impregnated with adrenalin chloride (1 in 1,000) and the patient's head is raised. The bleeding is sometimes so profuse as to be positively terrifying; however, it invariably ceases in a short time.

When the ganglion has been removed, the dura mater is allowed to fall into place, when the bleeding will generally stop and the wound can be closed; as a rule no drainage tube is required, but if the bleeding persist in spite of elevation of the head, a small tube must be inserted just beneath the dura at the entrance to the skull; it may be removed in twenty-four hours. If the motor root of the nerve has been divided, it is unnecessary to suture the divided tendon of the temporal muscle, or to wire the zygoma in position, as both the temporal and the masseter muscles will be paralysed; the temporal tendon may be united with catgut sutures, however, should it be necessary, and the zygoma may be drilled and fastened with catgut. This will be done whenever it has been possible to save the motor root. If a drainage tube be inserted through the opening in the bone it should be brought out through one extremity of the incision. Large dressings are applied to the head, and a separate pad is fastened over the eye. When put back in bed the patient should be propped up in the sitting position for the first twelve or twenty-four hours.

After-treatment. There is usually considerable shock which, however, rarely proves fatal. It varies with the amount of blood lost at the time of the operation, and, in bad cases, it will be necessary to have recourse to subcutaneous saline infusion. In any case the patient should have an enema immediately after the operation containing 1 oz. of brandy, 1 oz. of strong coffee, and 2 oz. of beef tea, to which 30 min. of laudanum may be added. A saline rectal injection (10 oz.) at the body temperature may be given two hours later and repeated in four hours if necessary. The shock is rarely bad enough to call for intravenous infusion.

If a drainage tube has been inserted, it should be removed at the end of forty-eight hours at the latest; it is always best to dispense with one if possible, as cerebro-spinal fluid may continue to leak from the wound for some time if one be used. The dressing over the eye should be renewed, and the lids washed with boric lotion daily. The stitches may be taken out of the lids on the fourth or fifth day, but the eye should be kept protected by a dressing for at least three or four weeks after the operation. The stitches can be removed from the scalp wound about the ninth or tenth day, and the aperture in the skull needs no protection and soon becomes inconspicuous, being low down and well protected. If the motor root has been left undisturbed, the masseteric and the temporal muscles will not be paralysed; if this be the case the surgeon will have reunited the temporal muscle to the coronoid process and have fastened the zygoma in position before closing the wound, and as a result the patient may get good movement of the jaw. In most cases, however, the motor root is divided when the ganglion is removed, and the movement of the jaw is permanently defective. Little complaint is made of this inconvenience, however, as the relief of pain following removal of the ganglion far outweighs it.

Difficulties and dangers. The chief difficulty in the operation is *hæmorrhage*. In the early stages of the operation this is comparatively unimportant if the steps detailed above be followed. In Cushing's original method, however, in which the temporal muscle is stripped off the bone, there may be considerable bleeding from the divided branches of the temporal vessels even at this stage. The serious hæmorrhage occurs during the separation of the dura mater in order to expose the ganglion, and may arise either from a wound of the middle meningeal artery or damage to the cavernous sinus. Bleeding may also occur from the small (accessory) meningeal, which passes through the foramen ovale, when the third division is cut. Both these vessels may be secured either by ligature (see p. 595), or if that fail, by the application of Horsley's wax.

The most serious bleeding, however, is from the cavernous sinus, which is in close relation to the first and second divisions of the nerve; both branches run along its outer wall. In order to avoid injuring it the precautions given above should be strictly followed, and the most cautious manipulation, careful sponging, and perfect illumination must be secured if a clear view is to be obtained and injury to any structure save the ganglion itself is to be avoided. Wound of the cavernous sinus is followed not only by the most alarmingly profuse hæmorrhage at the time, but not infrequently by thrombosis of the sinus subsequently, a complication marked by proptosis, intense chemosis, retinal hæmorrhages, œdema over the mastoid region, and permanently impaired vision or temporary blindness; there is usually, also, temporary paralysis of all the ocular muscles. Should such an accident occur, the best plan is to plug the area from which the bleeding comes with a small piece of gauze and leave it in place for ten or fifteen minutes, after which the bleeding will generally cease spontaneously. It has happened, however, that the bleeding from this cause has been so free that the operation has had to be abandoned, and the wound packed with gauze which was removed at a subsequent dressing. It is, however, very unlikely that this procedure will be necessary, and it is generally possible to sew the wound up without a drainage tube, since the bleeding ceases when the dura mater is allowed to fall back into place.

Another complication is *shock*, which is generally associated with loss of blood. The precautions against this have already been given (see p. 591). It may be so severe as to prove fatal in old and broken-down subjects.

Sepsis has occurred in a fairly large proportion of cases and is generally attributed to the length of the operation, the proximity of the anæsthetic apparatus, the mouth, or the hairy scalp, &c. This is a complication that should not occur, and no surgeon should undertake the operation unless he is confident of his power to maintain rigid asepsis throughout.

The Hartley-Krause method. An omega-shaped incision is made with its base just above the level of the zygoma and extending between the external angular process in front and the tragus behind. The incision is carried down to the bone, the bleeding is arrested, and then the pericranium is retracted for about a quarter of an inch on either side of the incision throughout its whole extent. An osteoplastic flap is then raised in the following manner:—

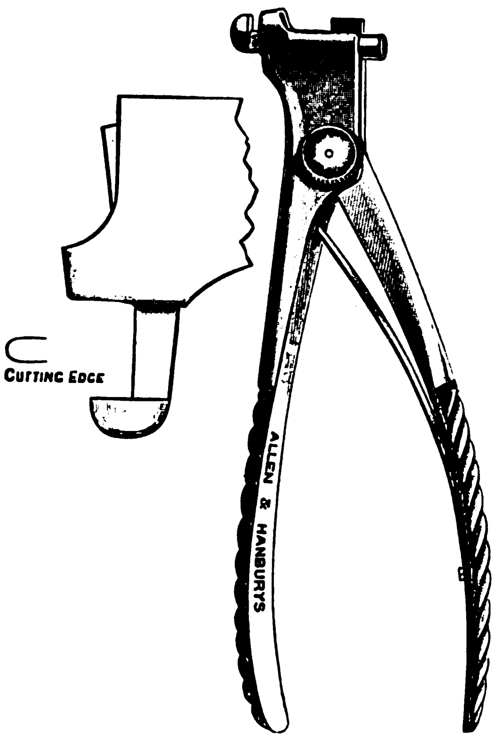

FIG. 240. DE VILBISS'S SKULL FORCEPS. These will cut a track through the skull the width of the cutting edge of the blade. They are very powerful and the work can be done rapidly.

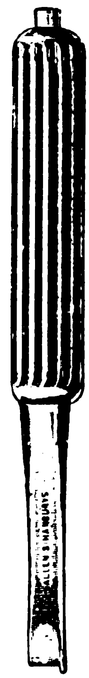

FIG. 241. GUARDED CHISEL FOR SKULL OPERATIONS. The probe-like projection is inserted between the dura mater and the bone. The chisel can only be used from a large trephine hole.

A half-inch trephine hole is made at the two top corners of the proposed bone-flap, and these are connected by a horizontal incision made through the skull either with forceps, such as those of De Vilbiss (see Fig. 240), or a guarded chisel (see Fig. 241); the former method is preferable, as being more rapid. Other methods of dividing the skull are by means of Gigli's wire saw, which must be protected from wounding the dura mater by passing a flexible metal guide between it and the bone, or by Hey's saw, which is, however, a very tedious method. From each trephine hole a vertical incision, made in the same way, is carried down to the base of the bone flap; some surgeons make a trephine hole at each inferior angle also, but this is unnecessary. A rectangular portion of bone is thus divided from the surrounding skull around three of its sides and only remains attached by its base; this, being thin, can be fractured by levering the bone flap outwards with a strong elevator introduced into the upper horizontal cut. In this way a flap is

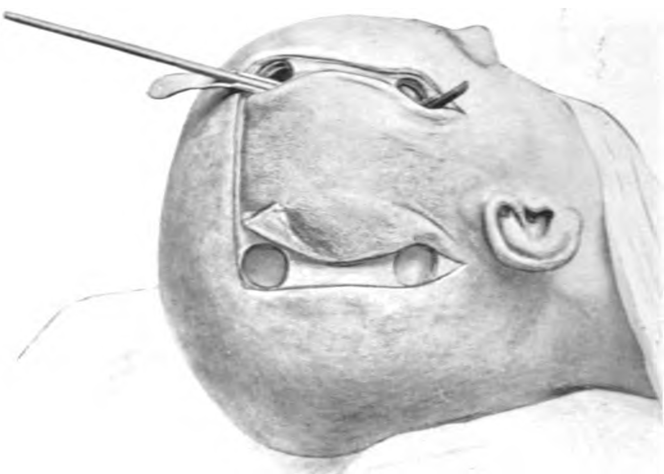

FIG. 242. GIGLI'S WIRE SAW INTRODUCER. This figure (for which I am indebted to Mr. Louis B. Rawling) shows the flexible whalebone introducer in place with the metal guard over it, preliminary to drawing the saw into place by means of the whalebone guide. It will be noticed that the operation here illustrated is not for removal of the Gasserian ganglion. It illustrates Mr. Rawling's description of the formation of osteoplastic flaps.

reflected which consists of the scalp and the subjacent area of the skull, the latter still maintaining its vascular connexions with the soft parts (see Fig. 243). The reflected flap should be covered with a sterilized cloth during the operation, at the end of which it can be replaced accurately by merely turning it up into position; owing to the fact that the vascular connexion between the bone and the soft parts is unimpaired, the bone does not undergo necrosis unless the wound becomes septic. If the flap be cut in the manner above indicated the length of time taken by the operation is only increased by about twenty to thirty minutes. The important practical point is to make the flap large enough in the first instance to enable the manipulations to be carried out successfully without any necessity for enlarging the opening in the bone subsequently. The reason why an osteoplastic flap is useful in this operation and not in the preceding one is that the opening is higher up on the side of the skull and therefore needs protection.

The reflection of the osteoplastic flap exposes the dura mater, which must be lifted out of the middle fossa of the base of the skull until the ganglion and its branches are exposed and can be treated in the manner

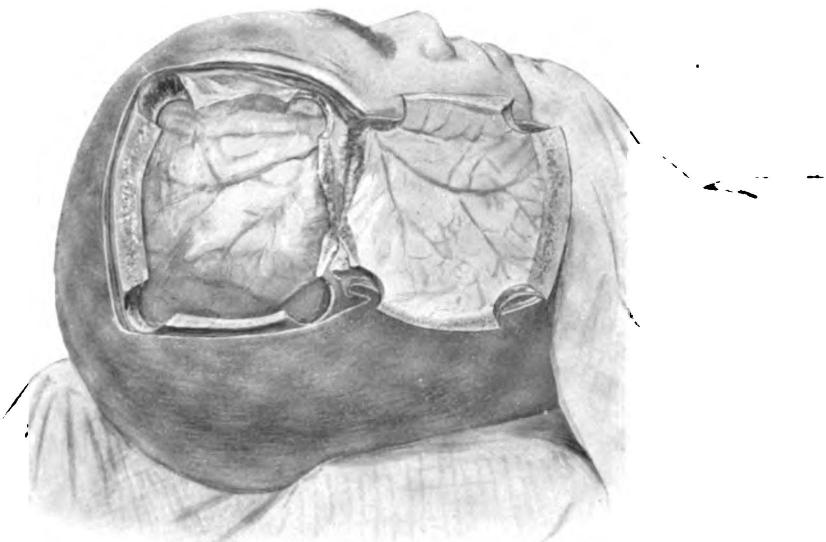

FIG. 243. OSTEOPLASTIC FLAP REFLECTED. The base has been broken through and the flap thrown down. This is another of Mr. Rawling's illustrations, and the method employed differs in slight particulars from that described in the text.

already described (see p. 595). The task of raising the dura from the bone is more tedious and difficult than in the method first described, owing to the fact that in the operation under consideration (Hartley-Krause) the skull is opened higher up and therefore considerable compression has to be applied to the superjacent brain, which has to be pressed out of the way in order to get proper access to the nerves and the ganglion.

Doyen's method. In this operation the sickle-shaped incision (Fig. 235) already described (see p. 593) is employed. After the skin flap has been reflected, the zygoma and the coronoid process are divided, just as in Cushing's operation. The third division of the fifth is then identified at its exit from the skull and cut as long as possible, and a stout silk ligature fastened to its proximal end. The internal maxillary artery is tied close to its origin. The skull is opened on the level of the temporo-sphenoidal suture with a trephine, after which that portion of the greater wing of the sphenoid and the squamous portion of the temporal bone intervening between the opening in the skull and the foramen ovale (see Fig. 244) is cut away with powerful cutting-pliers or a chisel or gouge, the dura being raised and protected from injury by a fine spatula. When

FIG. 244. DOYEN'S BONE SECTION FOR REMOVAL OF THE GASSERIAN GANGLION. The circular incision is the trephine opening.

the outer margin of the foramen ovale has been removed, traction upon the third division guides the surgeon to the ganglion, which is raised from its bed, divided at its junction with the trunk of the trigeminal, pulled forwards, and removed by cutting across its three branches on the distal side of the ganglion.

In this operation it is rather easier to avoid wounding the cavernous sinus, but the bleeding from the pterygoid plexus of veins is usually severe, and the field of operation is somewhat cramped and difficult to keep bloodless. Firm packing and the free use of adrenalin will be necessary.

Results. On the whole the results of removal of the Gasserian ganglion are favourable, although the death-rate in the past has been considerable. This should improve in the future, as a number of the deaths appear to have been due entirely to sepsis. Abbé (*Annals of Surgery*, vol. xxxvii, 1903, p. 1), quoting from Lexer (*Archiv f. klin. Chir.*, vol. lxv, p. 1902), says that of 201 cases collected by Türk 85 per cent. survived the operation and 77.6 per cent. were permanently cured; 17 died on the table, 11 without regaining consciousness; 9 died of sepsis, 1 of hæmorrhage, 2 of brain tumour, 2 of post-operative pneumonia, 1 of heart failure, 1 of uræmia, and 1 of cerebral softening.

The immediate effect of the operation is loss of sensation over the affected side of the face, but this is considerably diminished in the course of a few weeks. The chief trouble is ulceration of the cornea on the affected side, which, however, is not a necessary accompaniment of the operation, and is best guarded against by keeping the eye well protected from the light and from all forms of irritation, however slight. At the operation, and for the first four or five days following it, the eye is protected by stitching the lids together (see p. 592). After the stitches have been removed, the conjunctiva is washed twice or three times a day with warm boric lotion, and the eye protected by a pad and bandage for three weeks or longer. The patient should wear protective glasses for the rest of his life, as the least irritation of the insensitive cornea may end in loss of the eye.

Recurrence of the pain rarely occurs when the ganglion has been completely removed. It may spread to the opposite side, and it has been known to spread to other nerves, but as a rule the arrest of the neuralgia in the affected region is permanent, provided always that the whole of the ganglion has been removed; there should be no great difficulty about making sure of complete removal if the steps enumerated above be carefully followed.

AVULSION OF THE SENSORY ROOT (Spiller-Frazier)

Physiological extirpation of the Gasserian ganglion, as von Gebruchten paraphrased this operation, is based upon the inability on the part of the sensory root to regenerate itself once divided. This operation upon the sensory root, proposed by Spiller in 1899, was put to the test in the experimental laboratory by Frazier and, after substantiating all that was claimed for it, Frazier adopted it in his own clinic in 1901. The advantages of the sensory root operation over extirpation of the ganglion are briefly these: (1) There is no risk of injuring the third, fourth, or sixth cranial nerves or the cavernous sinus; (2) the incidence of trophic keratitis is less because there are trophic centres in the ganglion which preside over the cornea and, if the ganglion is left *in situ*, these are not disturbed; (3) hæmorrhage is reduced to a minimum, since the ganglion need not be lifted from its bed, as in gangliectomy; (4) the various steps essential to the removal of the ganglion are avoided, thus eliminating technical difficulties and economizing time; (5) simplification of technical details, minimizing hæmorrhage and economizing time have served to reduce a mortality once 22 per cent., later 5 per cent., to zero. Frazier has not had a death in his clinic in his series of sensory root operations in the past five years.

The operation is performed as follows: Under ether anæsthesia. drop method, the patient is placed on an operating chair in the sitting posture, the head being fixed securely by an appropriate head rest. The approach to the ganglion is designed in the first place to avoid injury to the upper branches of the fascial nerve and, in the second, to secure a direct point of attack from the middle of the zygoma. The cutaneous incision starts at the hair line three to four centimetres above the zygoma and following somewhat the course of an interrogation mark, curves upwards, backwards, and downwards to the zygoma just in front of the external auditory meatus. From this point the incision extends forward along its upper margin to the middle of the zygoma. This horizontal extension of the cutaneous incision should not extend farther forward than a line drawn from the tip of the mastoid process to the supraorbital ridge. The cutaneous flap is reflected forward, exposing the temporal fascia and muscle. The incision in these structures is made in a fashion somewhat the reverse of the skin incision. Beginning above, at the upper margin of the cutaneous incision, a curved incision convexing forward is made down to the zygoma. The muscle is then divided from one to two centimetres from the mid-point of the zygoma backward and parallel with it. Thus two flaps are fashioned, a cutaneous flap reflected forward and a muscular flap reflected backward. An opening made in the temporal bone with a Hudson drill is enlarged to the size of a fifty-cent piece, the lower margin of the opening extending to the base of the skull. The dura is carefully separated from the base and the temporal lobe gently elevated until the foramen spinosum is reached. The latter is plugged with cotton or Horsley's wax and the middle meningeal artery divided. A little mesialward and to the front of the foramen spinosum the foramen ovale comes into view, through which passes the mandibular division. The dural reflexion over this is cut and with a blunt dissector the dura propria of the ganglion is elevated backward and mesialward until the sensory root is exposed. When the inner margin of the root has been exposed the entire root is picked up on a small blunt hook and with slight traction the root is severed from its central attachment. The purpose of the operation thus completed, hæmorrhage is controlled by suitable measures and the wound closed with tier sutures.

ANASTOMOSIS OF THE FACIAL NERVE

Indications. The distal portion of the facial nerve is frequently anastomosed with the hypoglossal or the spinal accessory nerves in cases of permanent facial paralysis, usually associated with middle-ear disease. The nerve is exposed and divided at its exit from the skull through the stylo-mastoid foramen, and the distal end is implanted into the hypoglossal or the spinal accessory nerve according to the wish of the operator. In the earlier cases the spinal accessory was chosen, but, owing to the greater difficulty of the operation and to the fact that associated movements of the shoulder followed restoration of function of the facial muscles and lasted for a long time, the hypoglossal is now generally preferred as the nerve for anastomosis.

This nerve has been stretched for the cure of facial tic, but as a rule the results are not permanent. The operation is usually followed by transient facial paralysis.

The facial nerve emerges from the stylo-mastoid foramen and passes forwards through the parotid gland, crossing the external carotid artery and the branches of the temporo-maxillary (posterior facial) vein in that structure. In the neck it gives off branches to the stylo-hyoid and the posterior belly of the digastric, as well as the posterior auricular nerve which turns up along the anterior border of the mastoid process in close connexion with the posterior auricular artery. In the parotid gland it breaks up into its terminal branches, which are distributed to the face.

Operation. The parts are shaved, the head is turned to the opposite side, and the pinna is pulled forcibly forwards. When the nerve is only to be stretched, an incision is made along the anterior margin of the mastoid process from the level of the centre of the external auditory meatus to its tip, and is curved forwards from this point to the angle of the jaw, thus marking out a somewhat crescentic flap with its convexity backwards. In thin subjects this flap is sufficient, but in fat ones it is generally advisable to make a second small incision forwards about an inch long and nearly at right angles to the former, just below the lobule of the ear, so that two small flaps are formed and a little more room is gained. When, however, the nerve is to be anastomosed either to the hypoglossal or to the spinal accessory nerve the incision should start on a level with the centre of the external auditory meatus, close along the anterior border of the mastoid, and follow down the anterior margin of the sterno-mastoid to the level of the hyoid bone; should it be found necessary, a second incision one inch long and at right angles to it should pass forwards from the centre of this to the angle of the jaw. The interval between the parotid gland and the anterior margin of the sterno-mastoid is defined, and the gland is pulled forwards whilst the muscle is drawn backwards. If the gland be displaced well forwards the posterior belly of the digastric will be seen crossing the wound, and its upper margin should be defined and the nerve sought for above it. This stage of the operation is often rendered difficult by free oozing from the posterior auricular vein and some of the venous branches in the parotid which will need ligature. When the upper border of the digastric has been identified, it is usually fairly easy to make out the nerve which crosses the wound obliquely from behind forwards. It is raised upon a small hook and stretched, or, if it is to be anastomosed, it is divided at its exit from the stylo-mastoid foramen by a blunt tenotome, and its distal end is brought down to the hypoglossal or the spinal accessory nerve and anastomosed to it (*vide infra*).

WITH THE HYPOGLOSSAL NERVE

The nerve should be exposed beneath the digastric and stylo-hyoid muscles, as it lies on the outer side of the internal carotid artery. This can be done by the same incision as for ligature of the lingual artery, but this only exposes its terminal portion, which is not used for the purpose of anastomosis. In order to expose it for anastomosis with the facial, the incision should be identical with that given above for exposure of the facial and should reach down as far as the great cornu of the hyoid bone.

The first stage of the operation is the exposure, identification, and division of the facial nerve (*vide supra*). When the facial has been identified and divided, the hypoglossal is sought for as it emerges from beneath the digastric and stylo-hyoid muscles and passes forwards to supply the muscles of the tongue, turning around the origin of the occipital artery from the external carotid; it is then traced upwards beneath the digastric from that point. Division of the digastric and stylo-hyoid facilitates the anastomosis greatly and seems to be harmless. When the nerve has been cleared, the divided distal end of the facial is brought into contact with it, a slit is made in its sheath, and the cut end of the facial is inserted into it and secured in the usual way (see p. 581). The greatest gentleness must be observed in the manipulations throughout.

WITH THE SPINAL ACCESSORY NERVE

The nerve leaves the cranial cavity through the jugular foramen in the same compartment of the dura mater as the pneumogastric, and runs down the neck between the internal carotid and the jugular vein.

After a short distance it passes obliquely downwards and backwards across the vein beneath the posterior belly of the digastric to the sterno-mastoid, the deep surface of which it pierces to pass obliquely through the muscle and cross the posterior triangle to become distributed to the trapezius. Its course is represented roughly by a line drawn at right angles to, and bisecting another line joining the tip of the mastoid process to the angle of the jaw. The nerve pierces the deep surface of the sterno-mastoid about two inches below the tip of the mastoid. It is very important to know the course of this nerve, as it is invariably involved in enlargement of glands in the upper part of the posterior triangle, and division of the nerve on the proximal side of the sterno-mastoid is followed by paralysis of the trapezius as well as by paralysis of that muscle.

A stout sand-bag is placed beneath the shoulders, the head is thrown a little back, and the chin is turned to the opposite side. The incision commences at the tip of the mastoid process, and is similar in all respects to that for exposure of the hypoglossal nerve (*vide supra*). The anterior border of this muscle having been defined, the deep cervical fascia is opened just in front of it throughout the whole length of the incision, and the muscle is drawn firmly back, the neck being slightly flexed to facilitate this. The posterior belly of the digastric is next identified as it crosses the wound, running obliquely downwards and forwards, and its lower margin is defined, when the nerve should be seen emerging from beneath it. Another useful landmark is the transverse process of the atlas, which can be felt easily with the finger and over which the nerve passes. Should the surgeon desire to anastomose the nerve to the facial, the spinal accessory is traced back as far as possible, the digastric and stylo-hyoid muscles being divided if necessary. The facial is then laid in apposition with the spinal accessory and grafted into it through a slit in its sheath (see p. 580).

This nerve is also occasionally divided and, still more rarely, stretched for the relief of spasmodic wry-neck. Stretching and simple division of the nerve are of little use, but resection of a portion has been followed by better results.

RESECTION OF THE POSTERIOR PRIMARY DIVISIONS OF THE FIRST THREE CERVICAL NERVES

Indications. This operation is sometimes an extension of the operation for resection of the spinal accessory for severe spasmodic tic; the steps of the operation by which these nerves are exposed and resected are well described by Professor Keen (*Annals of Surgery*, 1891).

Surgical anatomy. The posterior primary division of the first cervical nerve passes backwards between the occipital bone and the posterior arch of the atlas, and lies in the sub-occipital triangle below and behind the vertebral artery, under cover of the complexus (semispinalis capitis) muscle (see Fig. 245).

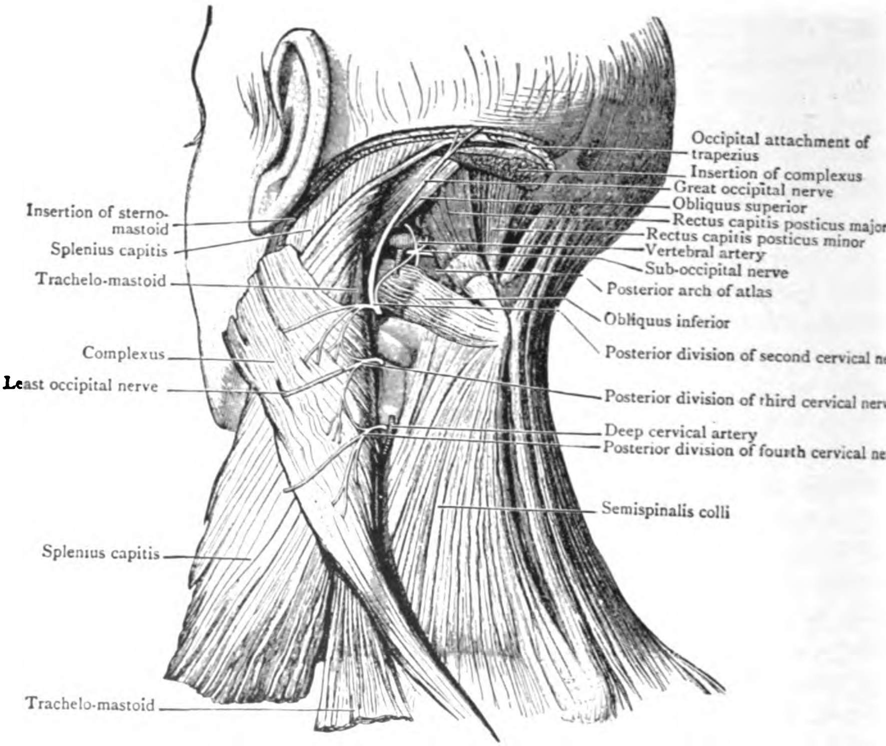

FIG. 245. POSTERIOR CERVICAL PLEXUS (Cunningham's *Anatomy*).

The posterior primary division of the second cervical nerve is the largest of all and passes backwards between the atlas and the axis below the obliquus inferior muscle. The complexus (semispinalis capitis) covers it and the semispinalis colli is to its inner side. The main trunk then pierces the complexus and the trapezius and becomes, as the greater occipital, the chief cutaneous nerve of the back of the scalp. It pierces the superficial fascia on the level of the superior curved line about an inch from the external occipital protuberance. It usually accompanies the occipital artery.

The posterior primary division of the third cervical nerve is much smaller than the second, with which it communicates by a loop.

Operation. Professor Keen recommends a transverse incision half an inch below the level of the lobule of the ear, commencing at the middle line of the neck behind, and running outwards for about two and a half to three inches. This, however, does not always give sufficient room to get a clear view of the structures, especially in a thick-necked subject, and a better plan is to raise a flap outwards from the middle line, which will expose the whole area concerned fully. An incision is made in the middle line of the neck behind, beginning about half an inch below the external occipital protuberance, and running vertically down for nearly three inches; from each end of this an incision about an inch and a half long is carried transversely outwards on to the neck. The flap thus marked out is dissected up.

The first nerve to be identified is the greater occipital, and this is found by dividing the trapezius horizontally near the upper limit of the incision, and finding the nerve as it emerges from the complexus (semispinalis capitis) about midway between the aponeurosis and the middle line. The complexus is divided transversely at the point at which the nerve emerges from it, and the latter is traced backwards until the posterior primary division of the second cervical is reached, when it is resected on the proximal side of the greater occipital, which is the larger of the two terminal branches into which it divides.

The next step is to identify the sub-occipital nerve, which is done by defining the boundaries of the sub-occipital triangle in which the nerve lies (see Fig. 245); they are the obliquus capitis inferior and superior, and the rectus capitis posticus (posterior) major. When found, the nerve is traced as far back as possible and resected. The final step is to identify and divide the third cervical nerve, which may be done by tracing down the loop between it and the second until the posterior primary division of the third is reached; it is then divided beneath the complexus (semispinalis capitis).

EXPOSURE OF THE BRACHIAL PLEXUS IN THE NECK (CERVICAL RIB)

Indications. This operation is rarely called for; it may be needed for a direct injury to the plexus, such as a stab, or for a laceration produced by violent traction upon the arm. More rarely still there may be pressure upon the plexus from a supernumerary cervical rib, or possibly from a tumour in the neck.

Operation. This is similar to that for the ligature of the third part of the subclavian artery (see p. 503). The position of the patient is the same as for that operation, viz. the head is turned to the opposite side and the arm is drawn down to its full extent. In a thin subject the cords of the brachial plexus can generally be felt beneath the skin in the supra-clavicular space, and may be exposed by making an almost vertical incision over the lower part of the posterior triangle midway between the adjacent borders of the sterno-mastoid and the trapezius. The external jugular vein will get in the way and may have to be ligatured; if so, this should be done well above the point at which it pierces the deep fascia. As the wound is deepened the plexus comes into view, and the outer border of the anterior scalene muscle can be defined. The transverse cervical artery and vein cross the wound transversely, parallel with the clavicle, and should be pulled downwards out of the way.

A second incision for exposure of a cervical rib may be used. The patient is placed in the same position and a horizontal incision above the clavicle is made. The dissection covers practically the same field. The thoracic duct and phrenic nerve are to be avoided as well as the pleura and subclavian. The vessels are drawn aside and the nerve root displaced sufficiently, so that complete resection of the false rib with cutting forceps is possible. It is necessary to divide its attachment both to the first rib and to the spine. Care should be taken to remove its periosteum so as to prevent regeneration. Unless great care is used in handling the nerves temporary paralysis is likely to ensue. If the pleura should be injured, complications seldom occur, although packing may be necessary.

Mr. C. A. Ballance showed at the Royal Society of Medicine on May 8, 1908, a child aged 5 years, upon whom he had operated for rupture of the upper cord of the brachial plexus which had occurred during childbirth. The deltoid, biceps, brachialis anticus, coracobrachialis, and supinator longus (brachio-radialis) were partly paralysed. The child was ten months of age at the time of the operation, which was in October, 1903. The fifth cervical was found to be ruptured just where it joins the sixth; after the ends had been freshened there was three-quarters of an inch between them, but by a little dissection the ends came together easily and were sutured with very fine silk. The nerves were identified at the operation by stimulation. The child was lost sight of immediately after the operation and only came under notice after four years' absence, when the paralysed muscles had completely recovered. In this case ten months had intervened between the injury and operation, and nevertheless the result was perfect. It tends to show that perfect results can be got by suture so long as it is possible to get good response to electric stimulation under an anæsthetic.

CHAPTER III

OPERATIONS UPON THE NERVES OF THE EXTREMITIES

EXPOSURE OF THE MEDIAN NERVE

Indications. The median nerve has frequently to be exposed in order to suture it after it has suffered accidental division. It may be reached in any of the following situations:—

(i) In the middle of the upper arm.
(ii) At the bend of the elbow.
(iii) Above the wrist.

Surgical anatomy. The nerve passes down the arm in close relation with the brachial artery, lying at first to its outer side, then crossing over the front of the artery about its middle, and finally lying to its inner side at the bend of the elbow, where it lies beneath the bicipital fascia (lacertus fibrosus of the biceps) and the median basilic vein. It enters the forearm between the two heads of the pronator radii teres and is separated from the ulnar artery by the deep head of that muscle. In the forearm it lies between the superficial and deep muscles, and at the front of the wrist it lies beneath and somewhat to the radial side of the palmaris longus tendon, between it and that of the flexor carpi radialis muscle.

In the middle of the arm. The operation in this situation does not require detailed notice as it is similar in all respects to exposure of the brachial artery in the middle of the upper arm (see p. 485). The median nerve will be exposed immediately before the artery is seen.

In the front of the elbow. The nerve will rarely require to be exposed in this situation, but, should such an operation be necessary, it is very similar to that for exposure of the brachial artery at the bend of the elbow (see p. 488). The incision, however, should be made about half an inch internal to the biceps tendon instead of close along its inner edge. The nerve will be exposed internal to the brachial artery beneath the bicipital fascia upon which lies the median basilic vein. It usually lies about a quarter of an inch internal to the brachial artery, and if the incision recommended above be adopted the nerve will be exposed directly and the artery may not be seen.

Above the front of the wrist. It is in this situation that the median nerve has to be exposed most frequently, as it is on the front of the wrist that the injuries to it usually occur. In order to repair damage of long standing to the median nerve it will be necessary to expose that structure where it is healthy and trace it down to the seat of injury. For this purpose it is exposed about a finger's breadth above the transverse crease on the front of the wrist as it is passing beneath the annular (transverse carpal) ligament. It lies either beneath or just to the radial side of the palmaris longus tendon, which can always be identified in the living subject, but which may be somewhat difficult to make out in the cadaver. In these cases a useful guide is the flexor carpi radialis, which can always be felt, and to the ulnar side of which the nerve is situated.

An incision about three-quarters of an inch long is made over the radial border of the palmaris longus tendon, the space between it and the flexor carpi radialis is opened up, and the nerve is seen lying somewhat deeply between them. The nerve is a large structure which may sometimes be mistaken for a tendon, but the difference in its colour will prevent mistakes. In this situation it is becoming somewhat flattened previous to dividing into its terminal branches.

EXPOSURE OF THE ULNAR NERVE

Indications. The ulnar nerve may have to be exposed in any part of its course, but it is generally damaged either in the ulnar groove at the back of the elbow or just above the wrist. In the former situation it is not infrequently involved in fractures or injuries about the elbow, but the most frequent lesion for which operation is required is partial or entire division of the nerve at the front of the wrist, in wounds caused by such accidents as putting the hand through a pane of glass. In recent cases, of course, there will be a wound which only needs to be enlarged in order to find the nerve. When, however, the case is of long standing the wound will have healed, and it will then be necessary to expose the nerve upon the proximal side of the cicatrix and to trace it down to where it becomes involved in the scar tissue. When the nerve is damaged above the elbow there is occasionally no wound, and the nerve has to be found from its anatomical guides.

Surgical anatomy. In the axilla the nerve lies between the axillary artery and vein, deep to them and to the internal (medial antebrachial) cutaneous nerve. It passes down in front of the triceps to the inner side of the brachial artery as far as the centre of the arm, where it pierces the internal inter-muscular septum along with the inferior profunda (superior ulnar collateral) artery to reach the interval between the olecranon and the internal condyle, where it lies in a deep bony groove protected by a special arch of deep fascia. It passes into the forearm between the heads of origin of the flexor carpi ulnaris and lies between that muscle and the flexor digitorum profundus, lying to the inner side of the ulnar artery.

The anatomical line of the nerve in the arm is from the junction of the anterior with the middle third of a vertical line let fall from the anterior to the posterior fold of the axilla, down to the groove behind the internal condyle of the humerus. In the forearm the course of the nerve is sufficiently accurately defined by drawing a line from the back of the internal condyle to the radial side of the pisiform bone.

In the upper arm. When the nerve has to be exposed anywhere in the upper half of the arm the operation requires no special description, since it resolves itself into exposure of the brachial artery (see p. 485), upon the inner side of which the ulnar nerve lies.

When it has to be exposed below the middle of the arm an incision is made upon the back of the limb as a prolongation upwards of the ulnar groove at the back of the condyle. The nerve can then be traced to the back of the condyle or to the point at which it pierces the internal inter-muscular septum.

In the forearm. Here the operation for exposing the nerve is similar in all respects to that for exposure of the ulnar artery (see p. 480), internal to which the nerve lies.

EXPOSURE OF THE MUSCULO-SPIRAL NERVE

Indications. This nerve is rarely divided by wounds or stabs, but it is not infrequently damaged in fractures of the shaft of the humerus owing to its close proximity to the bone as it winds round the humerus in the musculo-spiral groove. Its terminal branches may also be implicated in fractures of the external condyle of the humerus.

Surgical anatomy. In the axilla the nerve lies behind the axillary artery upon the subscapularis, teres major, and latissimus dorsi muscles. It passes backwards upon the long head of the triceps to reach the musculo-spiral groove along with the superior profunda artery, winding obliquely outwards and downwards to the lower third of the arm, where it pierces the external inter-muscular septum from behind forwards, and reaches the bend of the elbow in the interval between the brachialis anticus (brachialis) and the supinator longus (brachio-radialis). Beneath the latter muscle it divides into its two terminal branches, the radial (superficial radial) and the posterior interosseous (deep radial) nerves. The level at which this nerve divides varies considerably.

The nerve may require exposure either opposite the centre of the musculo-spiral groove, or in front of the elbow.

On the back of the arm. Perhaps the simplest plan is to expose the nerve about the centre of the groove by a vertical incision which separates the fibres of the triceps longitudinally. There are many incisions given, but on the whole this is the simplest and safest method, and it has the merit of being the most useful one in the majority of cases, as it is in fractures about the centre of the bone that the musculo-spiral nerve becomes implicated, either at the time of the accident or subsequently, in consequence of pressure from the callus.

FIG. 246. INCISION FOR EXPOSURE OF THE MUSCULO-SPIRAL NERVE AT THE BEND OF THE ELBOW. The forearm is fully pronated and the elbow is at an angle of 135°. The figure shows that the incision is a prolongation upwards of the radial border of the forearm.

The elbow is flexed to a right angle and the upper arm is held in the vertical position by an assistant. The surgeon makes an incision nearly four inches in length along the middle line of the posterior aspect of the arm, having its centre opposite the centre of the bone, that is to say, on a level with the insertion of the deltoid. The incision is deepened until the triceps is reached, and the muscular and tendinous fibres are then divided vertically, partly by the blade and partly by the handle of the knife, until the bone is reached, when the nerve will be seen lying in the musculo-spiral groove along with the superior profunda vessels and crossing the field of operation obliquely.

In this operation no muscular fibres are divided and the parts fall together easily after the operation is concluded.

In front of the elbow-joint. Exposure of the nerve in this situation may be required in cases of fracture involving the external condyle and damaging the nerve.

The elbow-joint is flexed to an angle of 135° and fully pronated by an assistant. An oblique incision is made across the lower end of the upper arm, the line being a direct continuation backwards of the outer or radial border of the forearm (see Fig. 246). If this incision be planned properly, and care be taken to pronate the limb fully, the interval between the supinator longus (brachio-radialis) on the outside, and the brachialis anticus (brachialis) on the inner side, will be hit off with little difficulty. When the interval between these two muscles is found—and it is usually denoted by a fatty interval in which small branches of the superior profunda are seen emerging—the muscles are separated by the handle of the knife, and the nerve is found in the

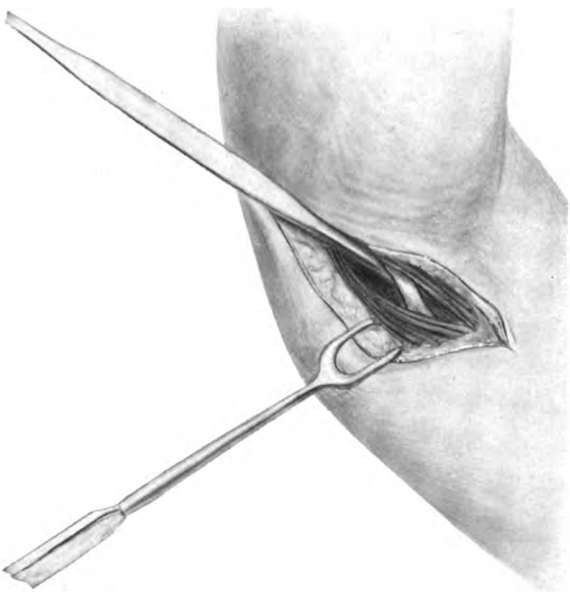

FIG. 247. EXPOSURE OF THE MUSCULO-SPIRAL NERVE IN FRONT OF THE ELBOW. The muscle on the left-hand side is the supinator longus (brachio-radialis), and that on the right is the brachialis anticus. The nerve lies deeply between the two.

interval between them crossing the incision almost vertically from above downwards (see Fig. 247).

Difficulties. This operation is difficult unless the interval between the two muscles mentioned above be hit off accurately. The supinator longus (brachio-radialis) has a long attachment to the external intermuscular septum and extends higher up the arm than one is apt to think; the inter-muscular septum between it and the brachialis anticus (brachialis) easily escapes notice, as the fibres of the two muscles run very much in the same direction. The position recommended above serves to define the supinator longus better than any other, and, if it be used, there should be little difficulty in finding the nerve.

EXPOSURE OF THE GREAT SCIATIC NERVE

Indications. The operation of stretching the great sciatic nerve either subcutaneously or after exposure by operation was formerly much in vogue for the relief of obstinate sciatica. At the present time, however, it is only rarely done, but it may be necessary, occasionally, for cases of simple sciatica which do not yield to medical treatment. For this purpose the nerve is exposed just below the fold of the buttock.

Surgical anatomy. The nerve emerges from the great sacro-sciatic foramen below the pyriformis muscle and extends from that point to its division into the internal and external popliteal branches. The level at which the division takes place varies considerably; it may occur nearly as low down as the popliteal space, whilst sometimes the two branches are distinct from the point of emergence of the nerve from the pelvis.

The surface line of the nerve is from the mid-point between the tuber ischii and the great trochanter to the centre of the popliteal space. In the buttock the nerve lies beneath the gluteus maximus and has the origin of the hamstring muscles internal to it. In the thigh it passes beneath the hamstrings and lies upon the adductor magnus. It is the strongest nerve in the body, and is nearly half an inch in breadth. It is said to be able to withstand a tensile strain of nearly 100 lbs. without rupture.

Operation. The patient lies as nearly flat upon his face as the exigencies of the anæsthetic will permit. The surgeon makes an incision four inches long in the line of the nerve (*vide supra*) running downwards from the fold of the buttock. It is important that the incision should not be made higher than this, for the lower edge of the gluteus maximus always extends a full inch below the fold of the buttock, and if the centre of the incision be made to lie over the gluteal fold, as it often is, the gluteus maximus will cover the whole of the wound, and this greatly interferes with the exposure of the nerve.

When the fat and the deep fascia of the buttock have been opened up, the coarse fibres of the gluteus maximus are seen running obliquely downwards and outwards. The lower border of this muscle is defined and pulled up with retractors, when the mass of the hamstring muscles will be found lying immediately beneath the incision but on a deeper plane than the gluteus maximus. The outer border of these is defined and the whole mass is pushed bodily inwards, when the firm rounded sciatic nerve is felt lying to their outer side and on a somewhat deeper plane still (see Fig. 248). In a muscular subject it will be necessary to flex the knee in order to relax the hamstrings sufficiently to allow them to be pulled well inwards. The sciatic nerve is easily recognized by its size and by the fact that it lies in a mass of fat and has comparatively large vessels (comes nervi ischiadici) over it.

A large blunt hook is now passed beneath the nerve, which is cleared by a few touches of the knife, the index and middle fingers are hooked beneath it, and the nerve is drawn well up to the surface. It is quite

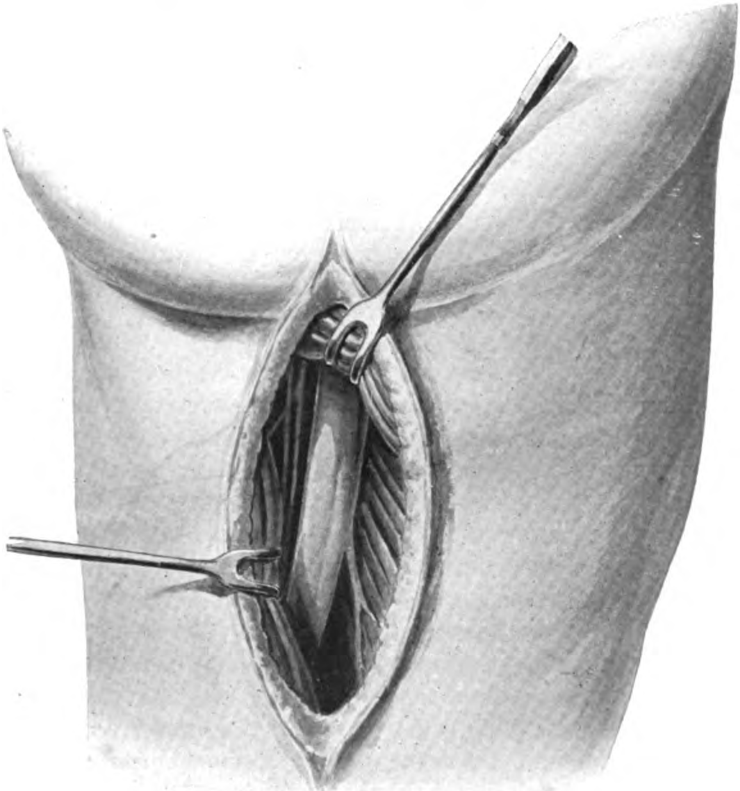

FIG. 248. EXPOSURE OF THE GREAT SCIATIC NERVE. The upper retractor pulls back the lower border of the gluteus maximus. The left-hand one is retracting the hamstring muscles. The great sciatic nerve lies beneath these.

safe to apply sufficient traction on the nerve to lift the limb off the table, but this should be done from the wound towards the extremity rather than towards the spine, as there is then no risk of tearing the nerve from the spinal cord; the nerve should be stretched in both directions, but only about half the pull should be exerted towards the spine. It should be stretched sufficiently to allow two fingers passed beneath it to lie flush with the skin of the back of the thigh. The wound is closed without a drainage tube. The paralysis produced by the stretching soon passes off.

EXPOSURE OF THE INTERNAL POPLITEAL (TIBIAL) NERVE

This is the direct continuation of the great sciatic nerve, and passes down the centre of the popliteal space to become the (posterior) tibial nerve at the lower border of the popliteus muscles. It may be exposed for the purpose of anastomosing it to the external branch (see p. 582). This nerve is so closely associated with the popliteal artery that the operation for exposing the nerve is similar in all respects to that required for the exposure of the artery. The nerve lies at first to the outer side, then behind, and finally to the inner side of the vessel. If it has to be exposed, the operation will be similar to that for ligature of the popliteal artery at the lower part of the popliteal space (see p. 441).

EXPOSURE OF THE EXTERNAL POPLITEAL (COMMON PERONEAL) NERVE

This terminal branch of the great sciatic lies close to the outer side of the popliteal space and crosses the outer head of the gastrocnemius to reach the neck of the fibula immediately behind or below the tendon of the biceps muscle. The nerve may be felt against the bone about an inch below the insertion of the tendon into the top of the fibula. It may require to be exposed in order to anastomose it into the internal trunk (see p. 582).

Operation. The limb is flexed and rotated fully inwards and a two-inch incision is made parallel to and half an inch behind the tendon of the biceps, the centre of the incision being over the point of insertion of the tendon into the bone. When the skin has been divided, the limb is flexed somewhat and the nerve will be found behind and below the tendon as soon as the deep fascia has been incised.

EXPOSURE OF THE ANTERIOR CRURAL (FEMORAL) NERVE

This nerve passes into the thigh beneath Poupart's ligament about half an inch to the outer side of the femoral artery, and lies between the psoas and iliacus muscles, the former of which separates it from the artery. It breaks up into its terminal branches about one inch below the ligament, and the incision to expose it should therefore commence above Poupart's ligament and should be about two inches in length, lying one inch external to the mid-point between the anterior superior iliac spine and the symphysis pubis. The nerve will be exposed as soon as the deep fascia has been divided.

SECTION VI

OPERATIONS UPON MUSCLES, TENDONS, TENDON SHEATHS, AND BURSÆ

BY

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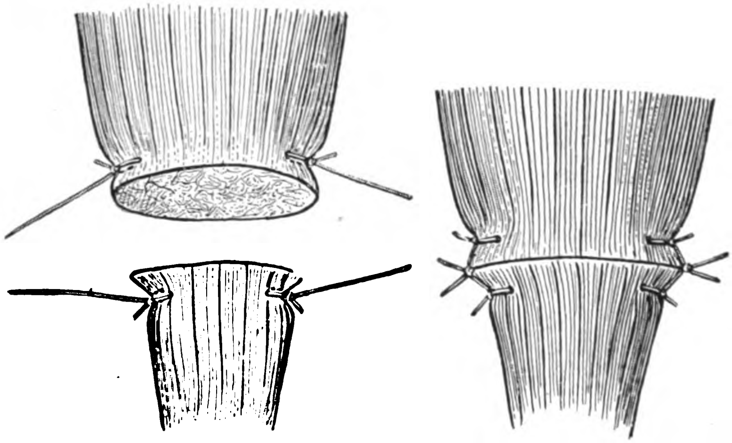
CHAPTER I

OPERATIONS UPON MUSCLES

MUSCLE SUTURE

Indications. (i) For the repair of muscles divided during the course of an operation.

Familiar examples of this are suture of the sterno-mastoid after ligature of the innominate by the ⅄-incision (see p. 496) or of the



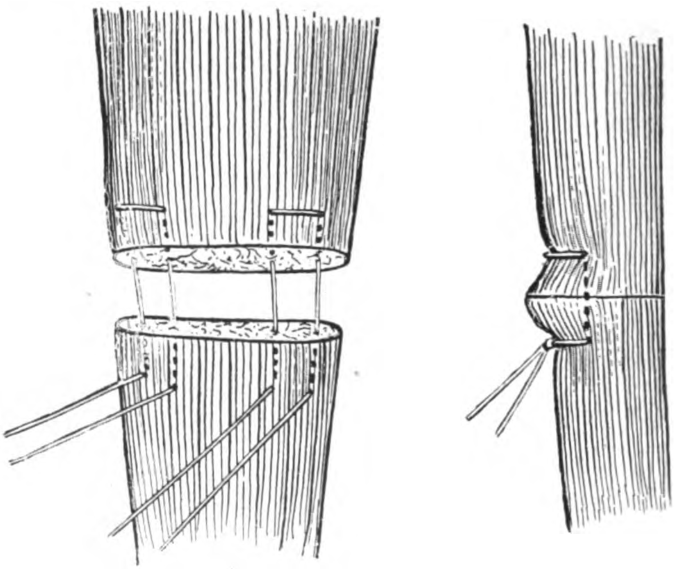
A B

FIG. 249. MUSCLE SUTURES. A shows the method of securing a suture on each side so that it will not tear out between the muscle fibres. B shows the method of approximating the divided ends of the muscle by tying the suture above to the corresponding one below. Quite firm traction can be employed, as there is no risk of the included mass of muscle slipping through the suture.

clavicular fibres of the pectoralis major after ligature of the first part of the axillary (see p. 490).

(ii) For the repair of muscles that have ruptured spontaneously, *e.g.* the biceps, rectus abdominis, &c.

Operation. Muscle is a difficult structure to suture satisfactorily. It is made up of bundles of parallel fibres, and the contraction of the muscle makes the sutures cut their way out very soon unless some special means are taken to prevent it. Practically there is no suture that will withstand the pull of the muscle except one that takes a firm grip of a portion of the muscular fibres before it is tied. A suture of the kind is seen in Fig. 249, and resembles in all respects that for suture of a tendon. The suture—moderately fine chromicized catgut is the best—is made to transfix a small portion of the edge of the muscle at right angles to its long axis about half an inch from the seat of rupture on one side, and that portion is tied moderately tightly in the suture, the ends of which are left long. A similar suture is now inserted on the opposite side of the rupture, and the ends of this suture are fastened to the ends



A B

Fig. 250. Mattress Sutures for uniting Muscle. A shows the method of introducing these sutures, which are of the ordinary mattress variety. The ends of the muscle are then approximated and the sutures are tied as is seen in B. The effect of tightening the suture is to cause a projection on the muscle as shown in the figure, which prevents the fibres escaping from the grasp of the suture.

of the former one, the limb meanwhile being put into a position in which the muscle will be relaxed to its utmost extent.

At least two, and preferably four, of these sutures should be inserted in order to take the pull of the muscle. Accurate coaptation may be effected by means of simple through-and-through sutures.

In flat muscles the mattress suture (see Fig. 250) may be useful occasionally, but the one first described will be generally employed. Whenever the muscle is tendinous in parts, the suture should take in the tendinous portion if possible.

There are a few practical points of importance that should be attended to if the best result is to be obtained. The gap in the muscle should never coincide with the skin incision if this can be avoided, as an adherent scar is very likely to follow, and this interferes materially with the working of the muscle. Therefore, when it is known that a muscle will have to be divided and reunited in the course of any operation, the two incisions must be planned so as to avoid correspondence. When the operation is done for subcutaneous rupture of a muscle, the gap should

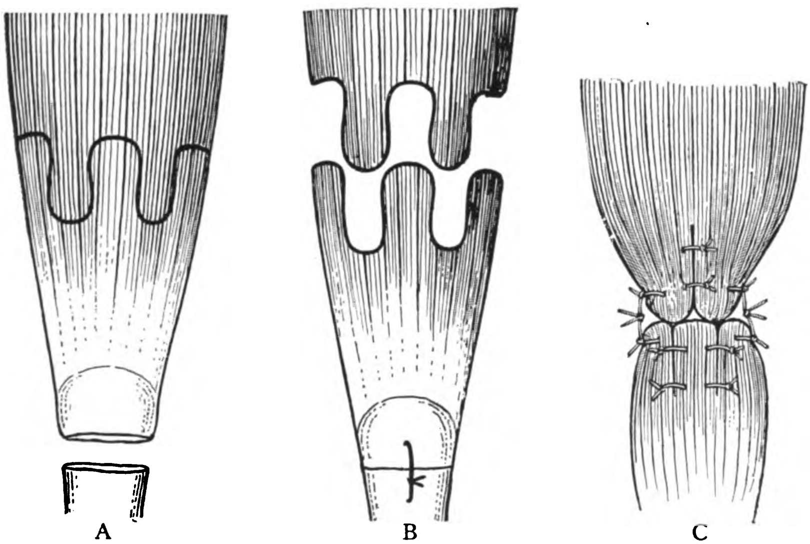


FIG. 251. MUSCLE-LENGTHENING. The method shown is the one described as the 'multiple cone' incision. A shows the manner in which the incision is made across the muscle, B the way in which the lengthening is produced after the incision. C shows the various projections united into one mass on each side of the incision and the two ends of the muscle then sutured by the stitch shown in Fig. 249. It is obvious that no incision through muscular tissue could approach the accuracy depicted in the diagram.

be exposed by raising a flap, the incision for which should be placed at some distance from the actual gap.

The strain on the line of union should be distributed as evenly as possible among the sutures, and a good number of these should be inserted so as to minimize the strain on any individual one. It is not necessary to cut away fibrous tissue between the ends in long-standing cases as it is in nerve suture.

The limb must always be put up on a splint that will relax the affected muscle to the utmost. It should be kept in the fully relaxed position for a fortnight, after which time it may be extended gradually.

MUSCLE-LENGTHENING

A muscle should never be lengthened when its tendon can be got at and treated in the same way; tendons unite much more satisfactorily than do muscles. It may possibly be called for in rupture of the biceps of long standing, where the contraction of the divided ends is extreme, although I have never met with a case in which the ends could not be brought into apposition by other means. It has been advocated for operations for long-standing fractures of the olecranon and patella, but Lord Lister's plan of gradual stretching is much better for the patella; in the olecranon the presence of the triceps aponeurosis makes the operation practically one of tendon-lengthening.

Operation. There are two methods of performing the operation. They are (*a*) the Λ-incision and (*b*) the 'multiple cone' incision.

(*a*) *The Λ-incision* is the simpler method and likely to give the better result. It may be used perhaps when there is difficulty in getting the fragments to meet in fractures of the olecranon of long standing. It gives ample lengthening, but the best results are likely to ensue where there is a good deal of fibrous aponeurosis in the muscle.

(*b*) *The 'multiple cone' incision.* This method is shown in Fig. 251, and is more valuable in theory than in practice. The difficulty is that the incision is through muscle fibre, and is therefore impossible to fashion with accuracy, while the net result is very little, owing to the contraction of the muscular fibres.

VON VOLKMANN'S CONTRACTURE

The views of authors have differed widely and the condition has been considered a primary muscle change (Volkmann, Leser), primary nerve affection (Choostek, Mannkopf, Lapinski), primary muscle and secondary nerve change (Hildebrand), and nerve and muscle degeneration simultaneously (Bardenhauer). However, that nerve pathology is not an essential part and when present is purely a complication is evident when one considers that nerve injury results in flaccid paralysis and contractures which are due to unopposed antagonists, while in Volkmann's contracture the loss of power and contracture are in the same muscle group. However, it has been stated that about 60 per cent. are accompanied by nerve injury, the median and ulnar furnishing most of the complications.

The pathology consists in a traumatic myositis characterized by hæmorrhage and effusion into the muscles followed by intense subfascial œdema which results in a fibrosis in the muscle group involved. Parts of the involved muscle group and parts of the individual muscles may be spared, and it is upon this fact that the principles of treatment are based. As pointed out by von Volkmann and emphasized by later authors, anything which adds constriction to the part predisposes to this traumatic myositis. Circular casts, tight bandages, and continued acute flexion of the elbow after injury in this region are in the histories of more than 50 per cent. of the cases. The damage is done within 24 to 48 hours and the chief evidence of its progress is pain.

Late cases present the claw hand with flexion of the phalanges and extension of the metacarpo-phalangeal joints. There is also a varying degree of flexion at the wrist and in extreme cases the forearm is slightly pronated and the elbow flexed. If the wrist is acutely flexed, the fingers in all but extreme cases may be straightened. Upon this fact depends the various non-operative treatments.

If loss of power in any muscle group occurs, immediate steps must be taken to prevent their contraction. This is accomplished by splints. Usually some contractile substance remains, and if the contraction of the fibrotic muscles is prevented the disability is reduced to a minimum.

The non-operative treatment of the established condition aims to stretch the contracted muscles. The Jones method follows:

Cut off zinc or sheet iron 5 splints which will fit the patient's fingers when extended. An assistant flexes the wrist fully. This relaxes and straightens the fingers, which are then separately splinted. The patient then attempts to extend the metacarpo-phalangeal range. After a few days this admits of splint from finger tips to wrist, the wrist fully flexed to apply this. Over finger splints attempts are then made to extend wrist. In several days splint to elbow is applied, the splint over others. By degrees extension is continued until the wrist can be fully extended with fingers straight. To maintain what is gained the metal splint is bent. After some weeks massage is instituted. This occasionally fails on account of deep structure fixation.

Taylor fits a brace over a plaster mould of the forearm. This is applied and by rubber bands extending from the fingers to a lever from the dorsum of the brace he obtains extension. The force can be regulated by the strength of the rubber band used and it is argued that slack is immediately taken up and stretching is constant and steady.

Operative measures consist chiefly in operations on the tendons lengthening those of the flexor group. This is done best by the double L or Z incision in the tendon. The operative site selected is just above the anterior annular ligament of the wrist. Success depends on observing the following principles: The deformity is corrected by lengthening the tendon so as to balance the opposing muscle groups. Transverse division of such portion of joint capsule or deep aponeurosis so as to permit full latitude of motion in wrist with fingers extended at time of operation. At times three inches of lengthening is necessary. If possible it is well to avoid division of adjacent tendons in the same plane. This lessens chances of adhesions. To prevent these it is well to make liberal free fat transplants, making a fat tunnel for each tendon extending well above and below the line of division. One may avoid cross suturing tendons by inserting immediately after division a suture. This is not tied until the sutures are complete at the end of the tendon operative work.

Shortening of the radius and ulna have been done, but the operation weakens the extensors and furnishes some added danger of infection and non-union.

Strict asepsis is essential to this open work, which is done with a constrictor applied.

It must be remembered that the majority of these cases are in children and that the bones may grow faster than the nutritionally impaired flexors, thus nullifying the correction.

The post-operative treatment is important; active motion is begun in 10 to 15 days and continued with mechano- and hydrotherapy to prevent further contraction.

The measures proposed assume the presence of some contractile portions in the involved muscle group. Concomitant nerve injury must be managed along the lines indicated by the condition.

CHAPTER II

OPERATIONS UPON TENDONS

TENOTOMY

Indications. Tenotomy, or division of a tendon, may be required:—

(i) For the relief of various deformities due to infantile paralysis. These may occur in any part of the body, but are commonest about the foot. In the majority of cases the tenotomy will be done by the subcutaneous method.

(ii) For the relief of deformities following upon cicatricial contractions from wounds, burns, &c. In these cases the open method should always be employed, as the parts are always distorted by the deformity, and great care is required in the identification of the structures divided.

(iii) For wry-neck of the permanent or non-spasmodic form. In these cases the sternal, and possibly the clavicular, head of the sterno-mastoid will require division, which should always be done by the open method.

(iv) For deformity resulting from spastic paraplegia. Cases of this kind are often improved by division of the tendons of the muscles that are in a state of spastic contraction; for example, walking may be greatly facilitated by division of the tendo Achillis.

(v) To prevent tilting of the heel after an operation such as Chopart's amputation; it is rarely used nowadays for this purpose, however.

A tendon may be divided either by the open or the subcutaneous method. In the former it is exposed by a suitable incision in the skin, and is then divided with an ordinary scalpel. In the latter method a special small knife called a tenotome (see Fig. 252) is introduced through a minute puncture in the skin, and the tendon is divided, the knife being guided merely by the sense of touch. Any tendon may be divided by either of these methods; formerly the subcutaneous method was almost invariably practised, because it was less likely to be followed by sepsis. It was generally recognized that when air did not gain free access to a wound, suppuration was unlikely to follow, and hence subcutaneous operations became popular. At the present time, however, this has no weight, and the merits of the open and subcutaneous methods have to be considered apart from the question of sepsis. Each has its distinct advantages and disadvantages.

The open method should be chosen:—

(i) When there are important structures in the immediate neighbourhood of the tendon which may be damaged by the tenotome. Examples of this are seen in the case of division of the sternal head of the sterno-mastoid, or of the biceps tendon in the leg. In each case

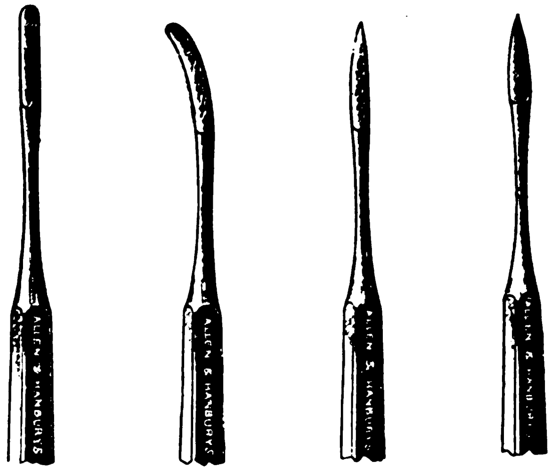


FIG. 252. TENOTOMES. The various forms of tenotomy knives are shown above. From left to right they are:—The straight blunt-pointed form, substituted for the sharp-pointed one when there are important structures to be avoided. Next comes the blunt-pointed curved tenotome, which is useful when a tendon lying over a curved bony surface has to be cut down upon from the front. The next in order is the ordinary sharp-pointed tenotome, and the one on the extreme right is the double-edged variety of the same instrument. The latter is particularly useful for division of ligaments, which it can divide by being moved from side to side.

a subcutaneous operation is fraught with great danger to important structures.

(ii) When division of a particular tendon is only a part of the operation required for the cure of the deformity. It not infrequently happens that, besides the tendon, the fascial structures in the neighbourhood, and sometimes the ligaments of a neighbouring joint, require division before the deformity can be properly corrected. An example of this is seen in wry-neck, where not only may both heads of the sterno-mastoid be affected, but the deep fascia of the neck, and even the sheath of the great vessels, may be so contracted as to require division; this can only be done by free exposure of the parts and most careful dissection. The tendency is to use the open method more frequently at the present time, as its great advantage is its certainty and safety. It has, however, the disadvantage that it leaves a wound that requires suturing and is therefore longer in healing and less sightly than the mere puncture left by the tenotome.

The subcutaneous method is exceedingly simple and is quite safe in suitable cases, while at the same time it is effective and leaves no scar. It is pre-eminently the operation for isolated and well-defined tendons which have no important structures in their immediate neighbourhood.

Certain precautions are necessary for due success in performing tenotomy. When it is desired that the divided tendon should subsequently reunite, as, for example, in the case of the tendo Achillis in talipes equinus, it is important that the division should not be practised where the tendon runs in a definite synovial sheath, such as those about the ankle or the front of the wrist. When a tendon is divided in these situations, the plastic material thrown out between the divided ends causes them to adhere to the synovial sheath, with the result that, although the ends may unite, the movement of the tendon is hampered, if not entirely destroyed, by its adhesion to the sheath. If, therefore, it be found necessary to divide a tendon within its synovial sheath, as may be the case, for example, in a contracted wrist, the operation should not be a simple tenotomy, but should be some form of tendon-lengthening, the tendon being exposed by slitting up its sheath, and measures being adopted to elongate it permanently (see p. 653).

DIVISION OF THE TENDO ACHILLIS

This operation is in common use and gives excellent results. It may be done by either the subcutaneous or the open method, the former being the one in almost universal use.

Indications. (i) The chief affection for which the tendo Achillis is divided is talipes equinus. As a rule the equinus is combined with some other deformity, such as varus or valgus, and division of the tendo Achillis may either be done at the time that the varus deformity is rectified, or, preferably, some time afterwards. This on the whole gives better results, as the firm support afforded by the tendo Achillis enables the surgeon to apply the stretching necessary to overcome the varus deformity. The equinus may be either congenital or may be the result of infantile paralysis; in some cases division of the tendo Achillis will be needed for the relief of spastic contraction of the calf muscles.

When the degree of equinus is extreme, and the gap following division of the tendo Achillis will be wide enough to lead to doubt as to whether the plastic exudation thrown out between the divided ends will give sufficiently firm uniting material, it is a question whether it is not better to abandon simple tenotomy in favour of one of the forms of tenoplasty with the object of lengthening the tendon (see p. 653). Personally, I should be inclined to make use of this latter method whenever the gap after simple tenotomy was likely to exceed three-quarters of an inch in length. It used to be the custom, however, to employ tenotomy, and after it to put the foot up at an obtuse angle to the leg, and only to bring it to a right angle by degrees.

(ii) The tendon has been divided at the end of Chopart's amputation to prevent tilting of the heel. This, however, is rarely necessary nowadays, partly because Chopart's operation is seldom done, but chiefly because the tilting of the heel occurring soon after this operation was mainly due to septic infection of the wound, and this no longer happens. The tendency to tilting at a later date is best avoided by stitching the extensor tendons to the stump.

(iii) Occasionally it may be necessary to divide the tendon in order to reduce a dislocation of the foot as in Pott's fracture, &c.

There are two methods of doing the operation:—

(*a*) By introducing the tenotome between the skin and the posterior surface of the tendon and cutting towards the tibia.

(*b*) By introducing the tenotome across the anterior surface of the tendon and cutting backwards towards the skin.

Each method has its own advocates, but there is very little to choose between them. In the former there is a little difficulty in running the tenotome between the tendon and the skin, and there is perhaps a little more risk of damaging the vessels as the last fibres of the tendon are divided. It has, however, the great advantage that it enables the surgeon to divide all tight fascial bands on the anterior surface of the tendon much more completely than is possible by the other method. On the other hand, if the tendon be divided from before backwards, it is easier to pass the tenotome across the flat anterior surface of the tendon and thus to avoid injuring the vessels. But the disadvantage of this method is that contracted fibres of the deep fascia and the tendon sheath may be left undivided, and therefore the operation will not always be as satisfactory as it should be. Moreover, an incautious cut on the part of the surgeon or an involuntary movement on the part of the patient may cause the knife to emerge through the skin and convert the tenotomy puncture into an open wound. In the tendo Achillis this is a distinct disadvantage, as it is apt to be followed by an adherent cicatrix. I prefer to divide the tendon from the skin towards the bone and have never experienced trouble from the proximity of the vessels.

Either operation may be done from the inner or the outer aspect of the limb, but usually the inner side is chosen for inserting the tenotome, as the vessels are then out of the way of the point of the knife, which necessarily traverses a wider arc than the hilt. In order to avoid damage to the subjacent parts by the point of the knife some surgeons are in the habit of employing two tenotomes, a sharp- and a blunt-pointed one, the latter being introduced flatwise along the sharp one, which is used to make the incision down to the tendon, until it is in position, when the sharp tenotome is withdrawn and the section completed with the blunt-pointed one.

Operation. After the parts have been disinfected, the foot is wrapped in a sterilized towel and an assistant grasps it with one hand, whilst he seizes the calf, which is also wrapped in a sterilized towel, in the other. The limb is either drawn over the end of the table or is well raised from it, and is rotated so that the inner border of the tendo Achillis looks vertically upwards, the outer border of the foot, therefore, being parallel with the surface of the table. The surgeon faces the heel, and, whilst the assistant puts the tendo Achillis on the stretch by bending the front of the foot upwards, he feels for its inner border and inserts a sharp tenotome, which should have a blade half an inch long, through the skin over it about one inch above the top of the os calcis. As soon as the puncture has been made the assistant relaxes the tendo Achillis by depressing the front of the foot, and the surgeon pushes the tenotome, the blade of which should lie flatwise against the tendon, carefully round between it and the skin under the guidance of his left index finger until its point can be felt immediately beneath the skin over the outer border of the tendon. The edge is then turned towards the tendon, and the assistant puts the tendo Achillis on the stretch once more by pressing up the front of the foot as forcibly as possible. The tendon is divided by a series of short cuts mainly with the point of the tenotome. As the division nears completion a definite gap can be felt by the left index finger which is kept on the posterior surface, and the last few fibres give way with a sudden snap, leaving a well-marked interval between the divided ends, so that the surgeon knows that the tendon is completely cut in two. Before withdrawing the tenotome the finger is inserted into the gap and any contracted fibrous bands deep to the tendo Achillis are felt for, and, if present, divided by a few touches with the point of the knife. A small pad of gauze is placed over the puncture in the skin and fastened on with collodion.

Difficulties and dangers. The chief one is a wound of the tibial vessels; this is only likely to occur if too large a tenotome be used, or if the knife be introduced from the outer side and its point be swept through too large an arc during the division of the tendon. The occurrence of this accident is recognized with some degree of certainty when a pulsating jet of arterial blood issues from the tenotomy puncture. It is easy to stop this bleeding by pressure, but it is probably better to enlarge the wound and find and secure the wounded vessel. This is better than trusting to pressure, as the vessel may be only partially divided and a traumatic aneurysm may follow; this would necessitate a subsequent operation. Moreover, the tenotome may have divided the nerve, which can be sutured forthwith.

The only other complication likely to be met with is that the knife may cut its way out through the skin as the last fibres of the tendon are divided. This is only likely to happen if the division be effected from the deep surface towards the skin, and then only if much vigour be exerted during division, or if the patient be incompletely anæsthetized. Should it happen, the wound must be sutured in the ordinary way.

After-treatment. The limb is put up with the foot at right angles to the leg upon a back-splint with a suitable foot-piece; in three or four days the tenotomy puncture will have healed. The limb may then be put up in some immovable apparatus for a month or six weeks, after which time the child may begin to walk. No violent exertion should be allowed for another month.

DIVISION OF THE TIBIALIS ANTICUS (ANTERIOR) TENDON

After passing through the innermost sheath in the anterior annular (laciniate) ligament this tendon crosses the front of the ankle-joint lying upon the astragalus (talus), scaphoid (navicular), and internal (first) cuneiform bones and the ligaments uniting them, to be inserted into the inner aspect of the internal (first) cuneiform and the adjacent base of the first metatarsal. As it passes beneath the annular (laciniate) ligament it possesses a definite synovial sheath which extends upwards for nearly two inches above the malleolus.

Indications. The tibialis anticus (anterior) is often contracted in talipes equino-varus, and, as it acts as a powerful adductor of the foot, it is usually necessary to divide it in order to overcome the varus.

Operation. The tendon is usually divided between the lower edge of the annular (laciniate) ligament and its insertion into the bone. It can be identified without difficulty and stands out in relief when the foot is abducted. Division is practised about three-quarters of an inch above its insertion into the internal (first) cuneiform, where it crosses the scaphoid (navicular). The tendon is commonly divided from the deep surface towards the skin, and it is usual to employ a blunt-pointed tenotome after the puncture in the skin has been made with a sharp one; this, however, is not a matter of practical importance.

The limb is fixed by an assistant, who stands on its outer side and grasps the front of the foot firmly with one hand and the leg with the other: he then puts the tendon on the stretch by plantar-flexing and abducting the toes. The surgeon stands on the opposite side and defines the outer edge of the tendon with his left index finger so that he may feel the point of the knife when it is passed across beneath the tendon. The sharp-pointed tenotome is thrust through the skin on the inner or plantar side of the tendon and passed across immediately beneath it, with its blade flatwise to the tendon, until its point is felt beneath the skin on the opposite side by the left forefinger; while this is being done the assistant relaxes the traction on the tendon. The edge of the tenotome is then turned towards the tendon and is made to cut towards the skin by short sawing movements, the tendon meanwhile being put firmly on the stretch again. When two tenotomes are used, the blunt-pointed one is passed flatwise along the sharp one after the latter is in position beneath the tendon; the sharp-pointed instrument is then withdrawn and the section of the tendon completed with the blunt one. The division is accompanied by a distinct snap and the appearance of a gap in the tendon.

The operation is very easy, as the tendon is small and rounded and the movements of the knife can be checked throughout by the left index finger placed upon the skin over it. No important structures are endangered and there is little risk of cutting through the skin when the tendon is divided. Even should this happen, the wound is comparatively small and can be sutured without difficulty. In ordinary cases a small pad of gauze or wool is fastened on with collodion; a few turns of a firmly applied bandage outside this will prevent any subcutaneous collection of blood.

DIVISION OF THE TIBIALIS POSTICUS (POSTERIOR) AND THE FLEXOR HALLUCIS LONGUS TENDONS

The tibialis posticus (posterior) tendon passes down along the posterior aspect of the tibia, occupying the first synovial sheath from its inner border. It passes in a special groove beneath the inner malleolus and the internal annular (laciniate) ligament, in which situation it has a well-marked synovial sheath. It is inserted into the scaphoid (navicular), the cuneiforms, the cuboid, and the second and fourth metatarsal bones. It is in relation to important structures, as external to it lies the tendon of the flexor digitorum longus, with the posterior tibial vessels and nerve immediately to its outer side. These structures lie so close together that an injudicious stroke of the knife dividing the tibialis posticus (posterior) tendon may damage the vessels.

It is the common practice to divide the tibialis posticus tendon above the annular ligament, an inch or more above the tip of the internal malleolus; here it is not only free of its synovial sheath, but the vessels are farthest away from it. It is still usually done by the subcutaneous method, but, considering the danger of wounding such an important structure as the posterior tibial nerve, it would seem better in all cases to expose it freely by the open method before dividing it.

Operation. *The subcutaneous method.* The assistant faces the front of the leg and grasps the front of the foot in one hand and the leg in the other; the limb is rotated outwards so that it rests on the outer side of the foot and the tendon is put on the stretch by dorsiflexing the foot. The surgeon feels for the tendon just behind the inner border of the tibia, and sinks the sharp-pointed tenotome vertically through the skin so that its blade shall pass flatwise between the bone and the tendon. The left index finger is pressed firmly below and behind the tendon so as to define and steady it, and the tenotome is pushed on until it has gone down quite to the level of its deep surface; the assistant meanwhile relaxes the tension. The cutting edge is now turned towards the tendon and this structure is divided from its deep surface towards the skin, the tendon being put firmly on the stretch once more. A blunt tenotome may be passed into the wound along the sharp one and the actual section of the tendon made with that. The flexor hallucis longus tendon lies so close outside that of the tibialis anticus that it is usually partially divided at the same time; this is not a matter of much importance, as the muscle is generally contracted and its tendon needs division also.

It is obvious that there is considerable risk of wounding the posterior tibial vessels and nerve which lie close to these two tendons. Although better fortune seems to have followed this operation than might have been expected, it is nevertheless advisable to abandon subcutaneous division in favour of the more certain open method, which can be practised through a very small opening and ensures perfect exposure of the parts, so that the surgeon can see and divide the tendon of either the tibialis posticus or the flexor hallucis longus without the least risk to any other structures.

The open operation is done through a small vertical incision, which need not be more than half or three-quarters of an inch in length immediately over the inner border of the tibia, which can always be felt even in the fattest subjects. The centre of this incision should be two inches above the tip of the internal malleolus, and in making it the internal (great) saphenous vein and nerve must be avoided. The deep fascia of the leg is opened, and the finger-tip inserted into the wound will feel the tendon of the tibialis posticus immediately behind the inner border of the tibia; this is caught up with a blunt hook and pulled into the wound, when it can be divided with scissors. If the flexor hallucis longus is to be divided also, this can be done by inserting the hook again, and seizing the next tendon to the one divided, which will be the one sought for. This is divided in its turn without any risk whatever to the posterior tibial vessels or nerve.

DIVISION OF THE PERONEI TENDONS

The two peronei tendons pass into the foot behind the outer malleolus, which they groove deeply as they run beneath it. They are contained in a common synovial sheath, the peroneus brevis being the upper of the two tendons. The synovial sheath extends from about an inch above the tip of the malleolus forwards into the foot. The peroneus longus crosses the foot obliquely in a special synovial sheath to be inserted into the under surface of the internal (first) cuneiform and the adjacent part of the base of the first metatarsal. The peroneus brevis is inserted into the tuberosity of the fifth metatarsal.

Indications. (i) The peronei rarely require division for contraction, although this may be necessary in some advanced cases of valgus due to infantile paralysis.

(ii) Much more frequently the peronei are divided as a preliminary to using them for the purpose of tendon-grafting. Sometimes the paralysed peronei have their tendons grafted on to sound muscles, whilst sometimes the sound peronei have tendons of paralysed muscles grafted on to them.

There are no important structures in relation with these tendons, and if simple tenotomy has to be practised both tendons will probably require division and the subcutaneous method may be safely employed.

Subcutaneous division. The assistant faces the limb and seizes the foot in one hand and the leg in the other. He presses up the toes and forcibly inverts the foot so as to put the peronei tendons on the stretch; the foot should rest upon its inner side on a sand-bag. The surgeon feels for the posterior margin of the fibula and introduces his tenotome in a somewhat slanting direction two inches above the tip of the external malleolus, so that the point travels a little backwards parallel with the surface of the fibula, which is somewhat oblique; as he does this, the assistant relaxes his pressure upon the foot so as to relax the peronei and to facilitate the passage of the tenotome between them and the bone. When the point of the knife has been carried well down to the inner edge of the tendons, its cutting edge is turned towards them and they are divided by cutting towards the skin, the tendons meanwhile being put firmly upon the stretch again. Here, as in the former case, the section may be completed by the blunt-pointed tenotome if desired.

When, however, tendon-grafting is to be employed, or when only one of the two tendons is to be divided, the *open method* must be employed. In this the tendons are exposed either by a small vertical incision directly over the posterior border of the fibula when simple division is to be practised, or by raising a semilunar flap with its base towards the fibula so as to give plenty of room for the tendon-grafting operation (see p. 664). In making this incision and in raising the flap the external saphenous vein and nerve must be looked for and preserved from harm, as they lie just behind the line of the peronei tendons.

DIVISION OF THE HAMSTRING TENDONS

Indications. (i) Division of one or more of the hamstrings is often required for the correction of contraction of the knee due either to injury, operation, or disease. For injury, division of the hamstrings is sometimes required to counteract their contraction in certain cases of fracture in the neighbourhood of the knee-joint, when this prevents the proper apposition of the fragments. In cases of disease the powerful hamstrings flex the knee and pull the tibia backwards and outwards, so that partial dislocation of the tibia on the femur occurs in neglected cases, and division of the tendons is necessary before this can be rectified. Occasionally, also, flexion of the knee occurs as the result of infantile paralysis, but this is not very common. After operations such as arthrectomy in children, however, it is quite common to get flexion of the knee; the tendency to flexion is extreme, and repeated divisions of the hamstrings may have to be performed before a permanently good result is obtained.

(ii) Division of the hamstring tendons may be a preliminary to an operation either for shortening these tendons or for tendon-grafting in infantile paralysis of the extensors of the knee.

Any of the three hamstring tendons may require to be divided, and in addition to them the tendons of the sartorius and the gracilis may need exposure for the purpose of either lengthening them or of grafting other tendons on to them.

Division of the biceps tendon. The biceps tendon is inserted into the head of the fibula and is the strong cord forming the outer boundary of the popliteal space and felt on the outer side of the knee when it is flexed against resistance. The tendon is divided into two parts by the external lateral (fibular) ligament of the knee-joint, and it is also connected with the popliteal fascia by strong fibrous bands running from its posterior border. Immediately along this border runs the external popliteal (peroneal) nerve, which can generally be felt quite distinct from the tendon as it passes down to the neck of the fibula. It is, however, so close to the tendon as to be easily endangered by subcutaneous division of that structure.

For this reason, if for no other, the subcutaneous operation should be avoided and the open one always practised when any operation upon the biceps tendon is contemplated. The subcutaneous operation will therefore not be described here, as it is dangerous even for simple division, while it is inefficient for cases in which there is any contraction of the surrounding tissues, as is not infrequently the case; it is obviously of no value if the tendon requires lengthening, as it frequently does in cases of contracted knee. In these cases an open incision allows an oblique section of the tendon to be made, after which the ends can be reunited (see p. 653), so that satisfactory union is assured. This should be done in perference to simple tenotomy in all cases in which there is a prospect of getting a movable knee-joint subsequently.

The open operation is done as follows: The limb is laid upon its inner and the surgeon faces its outer side. An incision about two inches long is made directly down upon the tendon if a tendon-lengthening or tendon-grafting is to be done, but one of about half an inch in length will suffice if the operation is to be a simple tenotomy. As the surgeon cuts down on the outer aspect of the tendon, this structure is made to stand well out in relief by attempting to extend the knee, and the tendon is readily defined and cleared owing to its large size. It is then easy to make certain that the nerve is not endangered, and the tendon can be divided with a scalpel, either transversely or obliquely. The finger introduced into the wound then defines any tense bands of fascia in the neighbourhood, especialy the ilio-tibial band which lies above and parallel to the biceps tendon. These are then divided through the same incision by pulling the skin edge to one side. This would not be permissible in the subcutaneous operation as numerous articular vessels, as well as the peroneal nerve, would be endangered. In the open operation, however, the vessels can be secured immediately they are divided.

Division of the semimembranosus and semitendinosus tendons. These two tendons form, with the sartorius and gracilis, the inner boundary of the popliteal space. The semitendinosus is smaller and more superficial, and is also placed rather nearer to the middle line of the popliteal space than the semimembranosus: the latter is, however, the largest of the hamstrings. The gracilis and sartorius are more laterally placed and are superficial, and their tendons are not so easily felt. These tendons may require division in the same affections as division of the biceps is practised for, and this is usually done at the corresponding spot on the opposite side of the popliteal space. In the case of these two tendons there is not the same strong objection to subcutaneous division if a simple tenotomy has to be performed, but even here it is better to employ the open method, as by it fascial bands are easily detected and divided. If the subcutaneous method be adopted, the tenotome should be introduced beneath the tendons and made to cut towards the skin. The steps of the open operation resemble that for division of the biceps.

DIVISION OF THE STERNO-MASTOID (WRY-NECK)

Indications: (i) Division of the muscle just above its origin from the clavicle and the sternum is practised for the cure of permanent wry-neck arising in early infancy. As a rule the two heads of origin of the muscle are affected unequally, the sternal portion being most contracted and becoming converted into a firm fibrous cord which stands out boldly beneath the skin. The shortening is due to the conversion of one or both heads of the muscle into fibrous tissue. The condition is therefore different to that of talipes due to infantile paralysis; there the contraction occurs in the healthy muscle, while in wry-neck it is the damaged one that undergoes contraction. The damage is usually the result of injury during child-birth or it may follow a gummatous infiltration later in life.

(ii) The muscle is sometimes divided in the course of other operations, such as ligature of the innominate artery (see p. 496).

Surgical anatomy. Division of the sterno-mastoid tendon is fraught with more danger to important structures than is the case with any other tenotomy usually practised. Three important veins are found in close connexion with it; close to its deep surface lies the internal jugular just where it joins the subclavian to become the innominate; the external jugular lies close behind its posterior border just before it pierces the deep fascia to join the subclavian vein; and the anterior jugular crosses its inner margin and passes behind it. Another important point has also to be remembered in connexion with this operation; the sterno-mastoid lies in a separate sheath of the deep cervical fascia, and this sheath is stout and often becomes firmly contracted also, so that it requires free division before the deformity can be satisfactorily rectified. Division of the cervical fascia cannot be carried out subcutaneously without risk of wounding one or more of the veins above mentioned, and therefore the subcutaneous operation is one of great hazard and uncertainty. It should be abandoned in favour of the open operation, which can be done with the minimum of risk and with the certainty that by its means alone proper division of all the contracted structures can be effected safely. The subcutaneous operation will therefore not be described.

Operation. The patient lies with the head thrown slightly back and the chin turned to the affected side; a small sand-bag placed beneath the root of the neck is the best way to put the tight muscle fully on the stretch. The breathing must be unembarrassed so that there shall be no

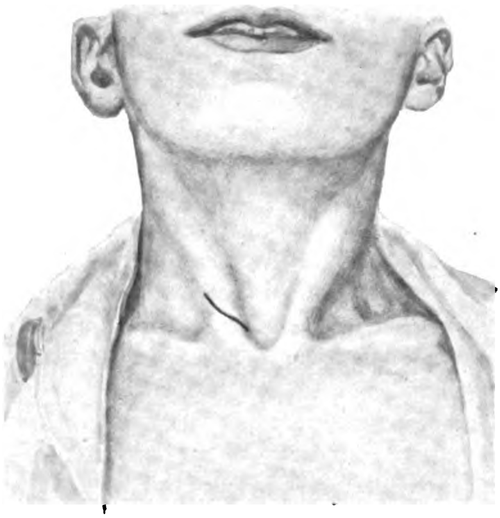


FIG. 253. INCISION FOR DIVISION OF THE STERNO-MASTOID. This incision gives ample room for either transverse or oblique division of the muscle and at the same time does not gape after the operation and leaves an inconspicuous scar.

venous engorgement, otherwise the bulging of the large veins at the root of the neck renders the operation dangerous.

Several different incisions may be used to expose the tendon. The one that I have found the most convenient on the whole is that shown in Fig. 253, passing obliquely across the lower end of the sterno-mastoid from above downwards and inwards, from the posterior to the anterior margins of the muscle, and terminating just above the sternal notch. Through this incision the whole area involved in the operation can be easily reached, and the resulting wound can be sutured without leaving any noticeable scar, a matter of some moment when the patient is a girl.

The skin and platysma are divided, and the margins of the shortened muscle are defined. Its anterior surface is then cut across transversely by steady strokes of the point of the knife, cutting from the superficial to the deep aspect of the tendon. There is no need to divide the muscle obliquely, as union between the divided ends is not required unless the entire muscle has to be divided; in that case the incision through the tendon should coincide with that through the skin, and then, when the divided ends have retracted, their extreme ends will just touch and may be sutured (see p. 654).

As the division approaches completion, a gap appears in the tendon and a careful look-out must be kept for the big veins which come into view in their sheath of fascia after the tendon has been divided. They can always be seen before there is any risk of wounding them, and it is a far better plan to divide the tendon from before backwards by cautious strokes of the knife as described above, than to attempt to run a director between the tendon and the veins, which might lead to a wound of the latter as the director passes across behind the tendon.

All the contracted part of the sterno-mastoid should be divided, whether it be one head or both, and when this is done the finger is introduced into the gap between the ends whilst the assistant puts the sterno-mastoid fully on the stretch, and any tight bands of fascia are defined and cautiously nicked with the point of a fine knife. This is the really dangerous part of the operation, as the tight fascial bands are frequently derived from the sheath of the internal jugular vein, and the latter structure may have to be laid bare for some distance before all the tight structures have been divided. It is, however, essential to the success of the operation that this should be done satisfactorily, as otherwise the neck cannot be straightened properly. In all advanced cases, especially in children who have been allowed to reach the age of twelve years or more, it will be found that the sheaths of the common carotid artery and the internal jugular vein are markedly contracted.

When the surgeon has satisfied himself that all resisting structures have been divided, the wound is closed with a few points of fine horse-hair, with Michel's sutures or, still better, by means of a sub-cuticular stitch which gives rise to the minimum amount of scar. Before the wound is closed, all bleeding must be arrested, and the patient should be allowed to come almost round from the anæsthetic; this allows coughing or vomiting to occur, and so tests whether any of the venous branches are oozing; every bleeding point must be tied, as otherwise a very unpleasant hæmatoma is likely to occur. A firm dressing is placed over the wound and tightly bandaged on so as to obliterate the small cavity left at the seat of division. The patient is put back to bed and the head is fixed so as to extend the contracted structures to the utmost;

that is to say, the head is turned with the chin towards the affected shoulder and the occiput towards the opposite side. It is kept in this position by sand-bags or by a suitable head-splint.

After-treatment. After the wound has healed, the patient will require treatment for the purpose of keeping the muscle on the stretch. This may be done partly by means of exercises in which the head is rotated actively or passively so as to stretch the affected muscle, and partly by wearing an apparatus which pulls the head mechanically into such a position as to put the muscle on the stretch; the apparatus may be worn at night, whilst the exercises suffice for the day. If the apparatus has to be worn during the day, as may be the case in severe degrees of the deformity, it need only be worn for the first six or eight weeks; after this time it should be worn at night for two or three months. The after-results are usually good, and if the operation be done before the well-marked hemi-atrophy of the face has occurred, there may be little to show that the trouble has ever existed. Much patience is required in the after-treatment, however.

MYOMECTOMY (MIKULICZ'S OPERATION)

American surgeons are strongly in favour of excision of a portion of the contracted tissue. The same incision as described above may be used. Through this the lower two-thirds of the sterno-mastoid is excised, *i.e.* up to the point at which the spinal accessory nerve passes through the muscle. After this excision the wound is closed and the head held by plaster casts in such a position as to separate the mastoid process and the sterno-clavicular joint most widely. This cast should be replaced from time to time, and the treatment continued for from two weeks to two months, varying with the extent of the bony changes in the spinal column, the persistence of the habit of holding the head in the improper position, and the intractability of the patient due to age or mental state.

Kanavel has described his method of treating these cases. It consists in the excision of muscle and contracted fascia, as described above, followed by the insertion of a free transplant of fat, taken from the abdomen or some fatty area. The transplant averages in size about one-half inch in thickness, an inch in width, and three to four inches in length. This entirely occupies the space left after the excision of tissue. The wound is closed tightly. The insertion of the fat restores the symmetry of the neck and permits the after-treatment of the patient without casts or other retentive apparatus.

The patient is instructed to carry the head in an over-corrected position, to take over-correcting exercises morning and night in front of a mirror for fifteen minutes each day. If the patient is too young to do this, the manœuvres are carried out by the parents.

SPASMODIC WRY-NECK

In spasmodic wry-neck, the operation of choice is the division of the spinal accessory nerve. The nerve emerges from the jugular foramen, passing downward and backward between the digastric muscle and the jugular vein, pierces the sterno-mastoid muscle and proceeds across the posterior triangle to the trapezius. Make an incision three inches long from a point just below the mastoid-process and running along the anterior border of the sterno-mastoid. Expose the muscle and divide the fascia.

FIG. 254. PHOTOGRAPH OF PATIENT WITH WRY-NECK BEFORE OPERATION. See Fig. 255. (*Kanavel.*)

The muscle should then be retracted and the transverse process of the atlas located under the digastric muscle. The nerve passes between the process and the digastric, emerging from beneath the muscle to enter the sterno-mastoid. The nerve thus exposed can be cut or a portion excised and the wound closed.

Division of the posterior nerve-roots of the cervical nerves can be done in very severe cases, the object being to paralyse the muscles involved. When the head is turned and extended the sterno-mastoid and trapezius of the affected side should be paralysed, and the splenius capitis, rectus capitis, complexus, superior and inferior oblique, posticus major, and trachelo-mastoid of the opposite side paralysed.

Robert Kennedy (*British Medical Journal,* October 3, 1908) has outlined a method of approaching the cervical nerves which gives a very satisfactory exposure; an incision is made three to four inches long midway between the external occipital protuberance and the external ear, extending downward from one-half inch above the superior curved line; expose the posterior edge of the sterno-mastoid and behind the sterno-mastoid the oblique fibres of the splenius capitis will be seen, care being taken to avoid the spinal accessory nerve. The splenius capitis is then divided with its subjacent connective tissue, exposing below the trachelo-mastoid's oblique fibres, and above, the longitudinal fibres of the complexus. The upper part of the wound is crossed by the occipital vessels, which form a triangle with the complexus and trachelo-mastoid; deep down in this triangle lies the superior oblique muscle. Then follow

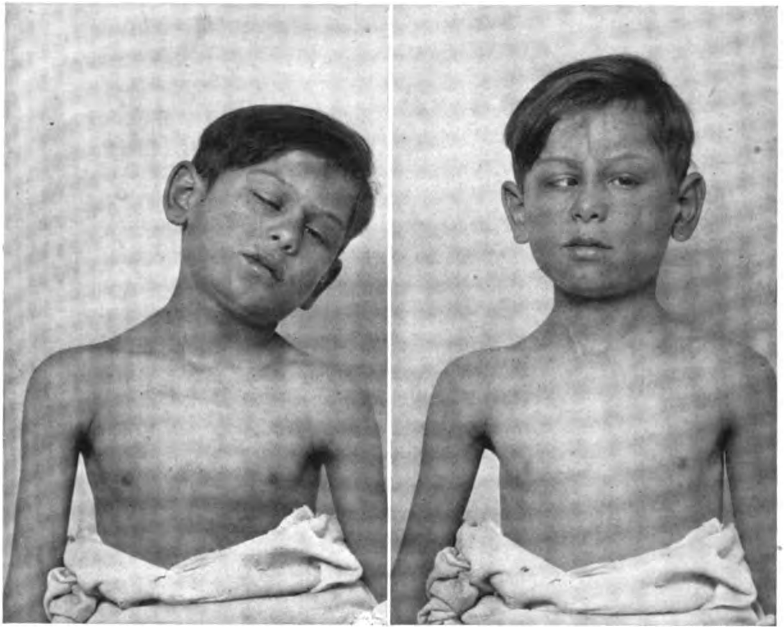


FIG. 255. PHOTOGRAPH OF PATIENT SHOWING RESULT AFTER INSERTION OF MUSCLE TRANSPLANTATION OF FAT, AND TREATED WITHOUT ANY RETENTIVE APPARATUS. Patient trained to use passive movements. (See Fig. 254.) (*Kanavel.*)

the complexus to its highest point of origin, which is the third cervical articular process; detach this from the third and fourth processes, retract the trachelo-mastoid and complexus, and observe several nerves entering the deep surface of the latter. The largest is the great occipital or internal branch of the posterior primary division of the second cervical, and this pierces the complexus about the level of the lower edge of the lobe of the ear. Above the point at which this nerve enters the complexus a slender branch can be seen entering the muscle and can be traced back to the posterior primary division of the first cervical nerve. The latter, however, is best found by tracing out the slender branch of communication with the second posterior primary division, which as a rule is present, passing upward from the second division across the inferior oblique. In order to deal satisfactorily with the sub-occipital nerve this communicating branch should be found early if possible and traced upward to the first division which lies between the vertebral artery and the arch of the atlas.

An imperfect result will be obtained of course unless the first division is accounted for. The third division can be reached by following down the short communicating branch from the second division. The fourth and fifth divisions will be found passing downward and backward close to the vertebræ. The nerves from the second downwards should be isolated to the point of separation into anterior and posterior primary divisions and no further. Care should be taken that no undue traction is put upon the anterior primary division, thus damaging it. The first nerve is sectioned just proximal to its branches and the others near their point of separation from the anterior primary division. In the majority of cases the distal portions of the nerves are excised as far as possible.

Kennedy further suggests, in acute cases of spasm which resist palliative treatment, temporary paralysis of the muscle by *dividing and immediately suturing* the spinal accessory of one side and the posterior primary divisions of the opposite side. The result is a partial degeneration of the affected muscles which later regenerate and resume their functions.

Dangers and difficulties. These have been sufficiently indicated in the description of the operation; practically the only one of any importance is a wound of one of the important veins in the vicinity of the muscle at the point of section. This accident is very serious in this particular situation as, owing to the influence of respiration and to the position of the veins, there is a great risk of air being drawn in through any puncture made in their wall, with the usually serious and probably fatal result. The accident, however, should never occur if proper care be taken to look out for the veins as the muscle is divided, and particularly if care be taken never to proceed with the division of the muscle or tight structures as long as the patient is coughing or the big veins are congested. Should the vein be wounded, the surgeon should at once put his finger upon the hole, so as to prevent the ingress of air; it may then be easy to pick up the wound in the wall of the vein and apply a lateral ligature to it which is quite efficient and which does not interfere with the circulation through the vessel. The vein will hardly ever be so badly wounded as to require complete ligature or even suture of its walls.

TENDON SUTURE

An operation for uniting the divided ends of a tendon may be called for under the following circumstances:—

(1) Soon after the tendon has been divided or ruptured and before the cut edges have had time to undergo any marked changes. This form of tendon suture is commonly known as 'immediate' or 'primary' suture in contradistinction to

(2) Those cases in which union is not practised until a considerable period has elapsed after the occurrence of the accident; in the meanwhile the ends have undergone definite changes. This is commonly known as 'remote' or 'secondary' suture.

PRIMARY TENDON SUTURE

Indications. (i) Among the cases that most frequently require primary suture are those in which the wrist tendons are divided by accidentally thrusting the hand through a pane of glass and thereby dividing the flexor tendons; division of the flexor or extensor tendons of the fingers by a knife is also of common occurrence.

(ii) Immediate tendon suture is necessary when a tendon has been divided accidentally or designedly during the course of an operation and the ends have to be brought together before its termination.

(iii) Some form of tendon suture has also to be employed in the operation for tendon transplantation (see p. 660).

(iv) In subcutaneous rupture of a tendon the ends should be sutured when the gap between them is large and the muscle concerned is an important one.

(v) After amputations of the fingers it may be necessary to join the flexor and extensor tendons together in order to retain the movements of the fingers.

The particular method of operation adopted for tendon suture will vary according as the divided ends of the tendon can be made to meet or not. In the former case all that is required is the best method of fastening the ends together under the circumstances; *i.e.* the operation is a simple tendon suture. In the second case, however, some form of tendon-lengthening or tenoplasty will be a necessary preliminary to the suture in order to approximate the ends sufficiently to suture them together. Tenoplasty or tendon-lengthening is often required in cases of secondary suture, but is only called for in cases of primary suture when portions of the tendon have been destroyed by the accident, *e.g.* a gunshot wound may carry away a portion of the tendon completely or so destroy it as to render it useless for suture purposes. As the steps of the operation vary according to whether the suture is primary or secondary, the two operations will be described separately.

There are three ways in which tendons can be united to one another; they are:—

(1) End-to-end union.

(2) Side-to-side union.

(3) Lateral implantation.

Of these the end-to-end method is the one almost invariably employed. It has the advantages that it does not shorten the tendon and that it is the method least calculated to alter its contour, a point of some importance when the latter runs in a definite groove or sheath.

The side-to-side method of anastomosis is excellent from the point of view of the strength of the anastomosis, but it has the great disadvantage that it causes a pronounced bulging at the seat of the anastomosis, and of course it also shortens the tendon to some extent. It is therefore chiefly used when there is a certain amount of slack in the tendon which can be safely taken up.

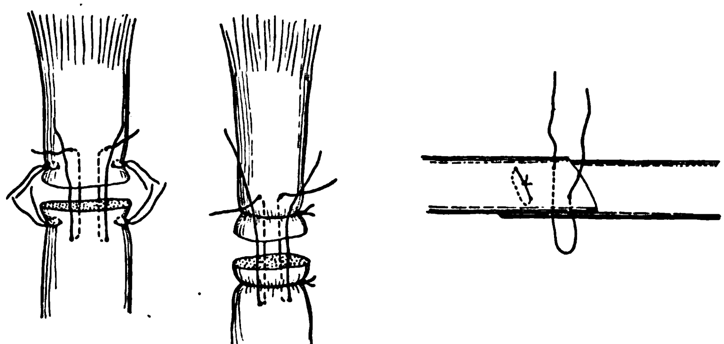
The implantation method is only used for tendon-grafting; it is peculiarly useful there, as by its means an absolutely firm union can be made that will stand considerable strain without any risk of separation.

Operation. After the wound has been sterilized and, if necessary, opened up sufficiently to allow easy access to the divided tendons, the surgeon identifies the ends and secures them with catch forceps in order to steady them during the act of suturing. Any bruised tissues should be clipped away when the wound is purified, so that there shall be no danger of sepsis occurring. In recent cases there is often some difficulty in defining the proximal end, as the muscle to which it is attached retracts to some extent and so widens the gap between the two ends. This, however, is not a serious difficulty, as the wound can be enlarged to any desired extent when the patient is under the anæsthetic. The chief trouble is in the palm, where there may be difficulty in finding both distal and proximal ends. As a rule the distal end is found fairly easily, as it does not retract, but in the case of the finger tendons, especially when they are divided in the palm, even the distal ends may be retracted out of sight if the tendons happen to be divided when the fingers are flexed; as the patient extends the fingers the distal end of the tendon is pulled up out of sight into the tendon sheath. Should this happen, pass a probe along the tendon sheath down to the site of the retracted end, make an incision into the sheath at this point, tie the tendon to the probe end, and then draw the tendon along the uncut sheath to the distal cut end. After union has been effected the sheath is sutured over the united tendon.

It may be possible to bring the divided proximal end into view by squeezing down the muscles of the forearm and firmly flexing the wrist. Should this prove unavailing, however, it will be best to expose the tendon sheaths above the annular ligament, when the tendons can be identified and either pushed down into the palm or pulled down by means of sinus forceps pushed up from the palmar wound. When the wound is at the wrist, however, there is little difficulty in defining both the divided ends after enlarging the wound.

In a case of subcutaneous rupture of a tendon, the gap between the divided ends should be exposed by a curved incision whereby a flap is raised, so that the resulting scar does not lie over the united ends of the tendon and there is, therefore, no risk of adhesion subsequently.

Suturing the tendons. As a rule no previous preparation or paring of the edges is necessary, as in the majority of cases the tendon will



A B C

FIG. 256. METHODS OF SIMPLE TENDON SUTURE. A shows the usual method described in the text. In B a constricting suture around each end prevents the vertical sutures from cutting out. C shows the mattress suture for flat tendons; here the ends overlap.

have been cleanly divided by a knife or other sharp instrument; if, however, the ends are ragged, as they may be if the rupture be a subcutaneous one, the edges should be trimmed with sharp scissors, and, if this has to be done, the line of section should be made as oblique as possible without sacrificing an unnecessary amount of tissue. The ends secured in forceps are brought into apposition ready for suture.

(1) *Lateral sutures.* It serves no useful purpose to pass the sutures through the whole thickness of each divided end and then simply to tie them together; the sutures cut their way out between the parallel bundles of fibrous tissue and only fray out the end of the tendon. In order to get a union that will stand the necessary strain, some means must be adopted for getting a firm hold on the tendon, so that the ends can be

fastened together without fear of the muscular movements tearing out the sutures. The best way to do this in my experience is by means of lateral ligatures (see Fig. 256).

These lateral sutures are passed as follows:—

A fully curved intestinal needle threaded with medium-sized catgut is made to pick up a small thickness of the tendon by introducing it transversely to its long axis about a quarter of an inch above the cut end. The tendinous bundles thus picked up are secured by knotting the suture firmly, and a similar suture is introduced and tied at a corresponding point in the tendon on the opposite side of the gap. It will be found that the two ligatures can be tied firmly together, and there will be no risk of their being pulled off the tendon to which they are attached. Two, three, or four of these sutures are applied according to the size of the tendon, and they are reinforced if necessary by sutures of the finest catgut, which adapt the edges accurately after the lateral sutures have taken off the tension. It is important to bring the tendon ends into apposition before the sutures are inserted, so as to make sure that each suture on the proximal side lies opposite to its corresponding suture on the distal portion: otherwise the tendon may be twisted upon itself.

(2) *The mattress suture.* This is an excellent method for uniting thin flat tendons, such as the extensors of the wrist. It gives a very firm union without much extra tension. The chief objection to the method is that there is a slight bulging at the anastomosis, but this is unavoidable in all thin flat tendons, and is not of great importance. The method of passing the mattress suture is shown in Fig. 256.

The material for suture is a matter of some little importance, as it should be strong enough to hold for some weeks but should be eventually absorbed; if it is not, it may cause irritation of the tissues. Formerly I employed silkworm-gut for this purpose, but I found that, as it never becomes absorbed, it sometimes causes irritation, especially in superficial tendons, and requires removal, and therefore I now use Lister's chromicized catgut, which holds for weeks but eventually becomes absorbed; I have never had any trouble with this material.

(3) *Kanavel's method.* By this method the sutures are so introduced and tied that none of the suture material appears on the surface and the knot is between the ends of the tendon.

Fairly heavy silk, which has been smeared with vaseline so as to make the suture slip more easily, is threaded on a straight needle. The needle is now passed into the end of the tendon somewhat to one side of the centre and passes out of the opposite side of the tendon about one-third inch from the cut end. It is then reinserted at the same point at which it made its exit, passing transversely across the long axis of the tendon and making its exit upon the opposite side about one-third of the way around, and is again reinserted at the point of exit coming out on the opposite side at the other third of the circumference. The needle is again reinserted at the same site, but now passes down and out the cut end of the tendon, not in the centre however, so as to cross the silk as originally inserted. The procedure is repeated with the other cut end.

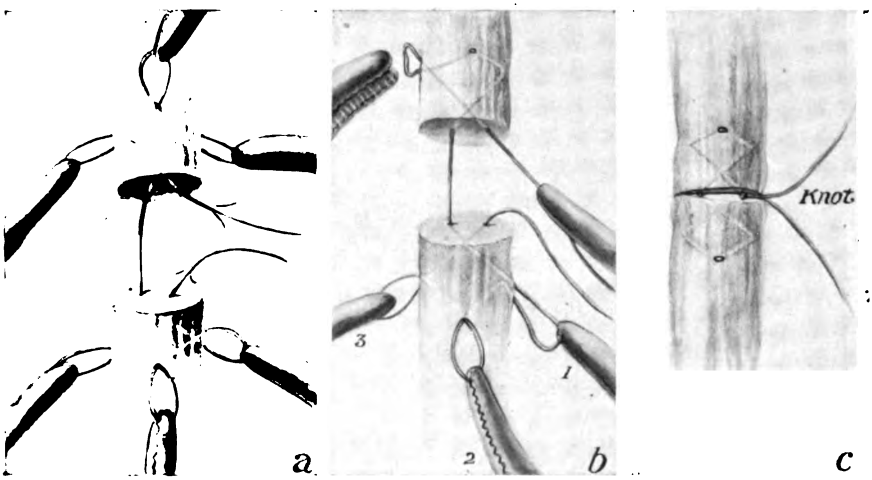


FIG. 257. KANAVEL'S TENDON SUTURE. Silk is so inserted, the knot being tied between the ends of the tendon, that none of the silk suture appears on the surface.

The distal suture end may be pulled tight at once, but on the proximal cut end the suture is not pulled tight at once because of the difficulty in making the suture slip easily and thus approximating the cut ends. The thread where it makes its exit on the sides of the proximal cut end is not pulled tight, but each of the three loops is held by a forceps. The assistant now brings the ends of the tendon together and loop 1 is pulled tight, then loop 2, and finally loop 3. The free ends are tied between the cut ends of the tendon. We thus have a suture which if carefully made does not have any suture material on the surface and has the knot buried between the cut ends. Reference to the illustration (Fig. 257) will show the steps of the procedure. It is especially valuable in the finger where the sutured ends must lie in a tendon sheath.

When accurate suture has been accomplished, the synovial sheath, if there be one, should be sutured over the tendon with the finest catgut. All bleeding points should be stopped, and in this connexion it is well to remember that an Esmarch bandage should not be used to obtain a bloodless field of operation, as the success of the operation largely depends upon obtaining a wound that is quite dry; the long-continued oozing that goes on after removal of an Esmarch bandage militates greatly against this. The wound should be sutured without a drainage tube, and the limb should be put up with the affected tendons in the relaxed position. Besides the advisability of this position from the point of view of the relief of tension, it should be remembered that, if adhesions occur between the tendon and its sheath when the muscle is in the stretched position, it is most difficult to restore movement subsequently, as it is impossible to break down the adhesions by further stretching; if, however, adhesions occur when the muscle is fully relaxed, movement under an anæsthetic will break them down easily. The position should be maintained if possible by the use of some flexible metal splint, so that the limb can be extended gradually during the first fortnight without the necessity for taking it off the splint and disturbing the dressing.

After-treatment. The wound should be dressed at the end of ten days, and the sutures removed. During this time the flexion will be gradually diminished; the limb is brought straight by the end of a fortnight. Massage and gentle passive movements should be practised as early as possible and active movements from the third week. No trouble arises from the death of the small portion of tissue strangulated by the ligature; union is firm in about six weeks, and the patient may use the affected muscle freely.

SECONDARY TENDON SUTURE

It not infrequently happens that the patient does not come under the surgeon's notice until some considerable time has elapsed since the occurrence of the accident, and this allows certain permanent changes to occur which necessitate rather different treatment. After the lapse of a week or a fortnight the proximal end of the tendon becomes permanently retracted, owing to the fact that its muscle, which is no longer kept on the stretch by the tension of its tendon, becomes shortened. The surgeon is then faced with two problems—(1) to find the divided ends, and (2) to overcome the shortening just referred to and to bring the ends together without tension.

Finding the divided ends. This is less difficult than it is to find the divided end of a nerve, but it is done in a similar manner. It is advisable to expose the parts by means of a crescentic incision which allows a flap to be dissected up so that the scars in the skin and subjacent parts will not lie over one another, and thus the chances of an adherent cicatrix and subsequent loss of movement are minimized. When there is no sheath to the tendon, a large flap is raised and the muscular fibres are traced to their insertion into the tendon, which is then defined and prepared for union.

When there is a sheath, the tendon is exposed in it well above the seat of the lesion, the sheath is slit up in the middle line with fine scissors, and the tendon is traced down until the divided end comes into view. The end, which is always adherent, is separated from the surrounding structures and prepared for suturing.

As a rule little preparation is needed before suturing, but when the ends have become rounded or irregular they may be freshened by paring them with a sharp knife. This, however, is not so important as in the case of immediate suture, because there is generally some considerable tension on the ends when an attempt is made to approximate them, and some form of tenoplasty will be required with the object of lengthening the tendon and so avoiding tension (*vide infra*).

When it is possible to bring the ends of the tendon into apposition without too great tension by simple flexion of the joints over which the muscles pass, the procedure is identical in all respects with that for primary suture (see p. 647). It is, however, most important to avoid tension when performing tendon suture, as the contractions of the muscle are liable to cause the sutures to cut out; therefore, when there is any marked tension, it is better to have recourse to tenoplasty or tendon-lengthening in order to bring the ends together without strain (*vide infra*). All the suture knots should be as small as possible and so placed that they are out of the way of friction. When the suture has been completed, the sheath should be united over the tendon with a continuous suture of the finest catgut, if possible. The limb is put up with the muscles fully relaxed and the after-treatment is similar to that for primary suture (see p. 647).

TENDON-LENGTHENING

Indications. The operation of tendon-lengthening may be required—

(i) As an adjunct to division of tendons which run in synovial sheaths in a contracted limb.

(ii) As a substitute for tenotomy when the gap left after it would be so great as to make successful union doubtful.

(iii) In some cases of secondary tendon suture where there is considerable tension upon the divided ends.

Operations. A number of ingenious methods have been devised for lengthening a tendon, but the following may be regarded as the most generally useful. In all cases the section should be made with a very sharp knife or with a skin-grafting razor, and great care must be taken to keep the wound aseptic, as very slight sepsis will lead to death of the portion of the tendon concerned and adhesion of the remainder.

(1) *Oblique section.* This is the simplest plan and is as satisfactory as any. Its usefulness, however, is in direct proportion to the thickness of the tendon concerned. When the latter is large and wide, such as the tendo Achillis, a very oblique section can be employed and considerable lengthening can thus be obtained (see Fig. 258). In the smaller tendons, however, only slight lengthening can be obtained in this way.

(2) *The* ⅂*-method.* This is a very useful method and gives a firm union. The disadvantage, however, is that it requires a fairly wide tendon for its most useful application; it is very suitable in the tendo Achillis, for instance (see Fig. 259).

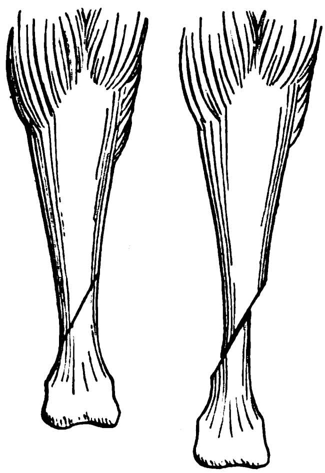


FIG. 258. TENDON-LENGTHENING BY OBLIQUE SUTURE. The amount of lengthening is determined by the obliquity of the suture, which in turn is largely governed by the width of the tendon.

(3) *Reflected slips.* Fig. 260 shows how the slips are reflected and sutured. The tendon may be lengthened by reflecting a slip from one end alone or from both; in the latter case considerable lengthening can be obtained. This method gives a rather weak union, but it has the advantage that a gap of almost any size can be bridged over by means of it; the reflected slips must be regarded more as a conducting than as an actual uniting medium. The union can be reinforced by bridging the gap across with one or two strands of catgut (see Fig. 261).

(4) *Hibbs's method.* Dowd (*Annals of Surgery,* 1906, vol. xliii, p 280) quotes the following simple method of lengthening a tendon from Hibbs, whose account originally appeared in the *American Medical News,* April 21, 1900. It can, of course, only be practised satisfactorily in a broad tendon, and is especially recommended for use in the tendo Achillis. It can be done very rapidly, and, as will be seen from Fig. 262, the tendon is not actually divided at all and therefore no sutures are absolutely necessary. It is, however, as well to surround the angles of reflection of the flaps with a ligature so as to prevent the reflected portion splitting away.

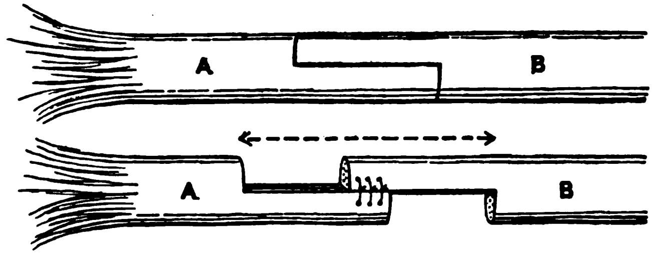


FIG. 259. THE ˥-METHOD OF TENDON-LENGTHENING. This gives a firm union, as the suture is lateral, not end to end. It requires a moderately stout tendon.

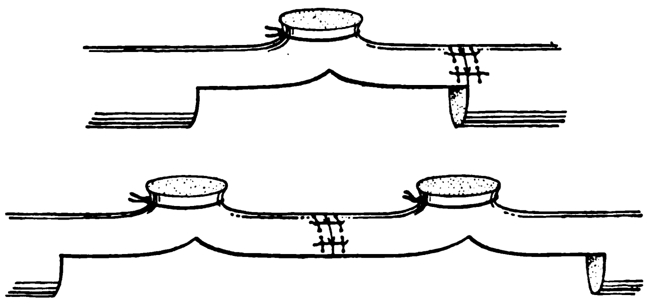


FIG. 260. TENDON-LENGTHENING BY REFLECTED SLIPS. The diagram shows the single and double methods. The reflected slips will be detached by the pull of the muscle unless they are secured by the encircling suture depicted above. The method by which end-to-end union of the slip is made is seen in Fig. 256.

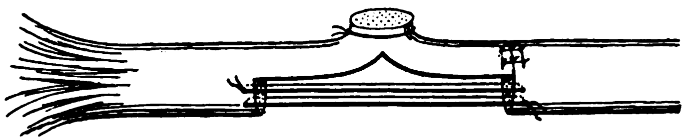


FIG. 261. REFLECTED SLIPS REINFORCED BY CATGUT SUTURES. The catgut sutures are merely used as a framework, not to strengthen the union mechanically.

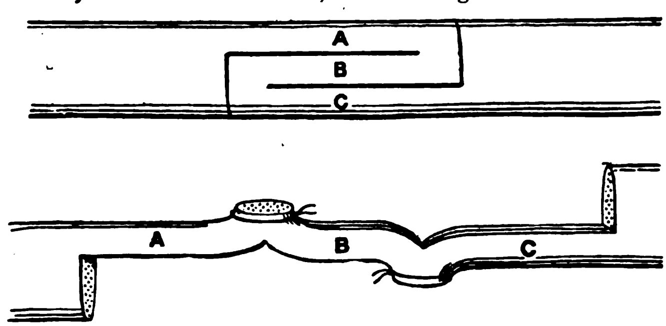


FIG. 262. HIBBS'S METHOD OF TENDON-LENGTHENING. The upper figure shows the incisions, the lower one their effect upon the tendon. The encircling ligatures must be used as before to prevent detachment.

(5) *Dawbarn's autoplastic grafting method.* This is an ingenious plan described by Dawbarn (*Annals of Surgery,* vol. xliii, p. 305), and is suited for cases of division of the flexor tendons in the fingers, particularly those in which a portion of both tendons has been completely lost.

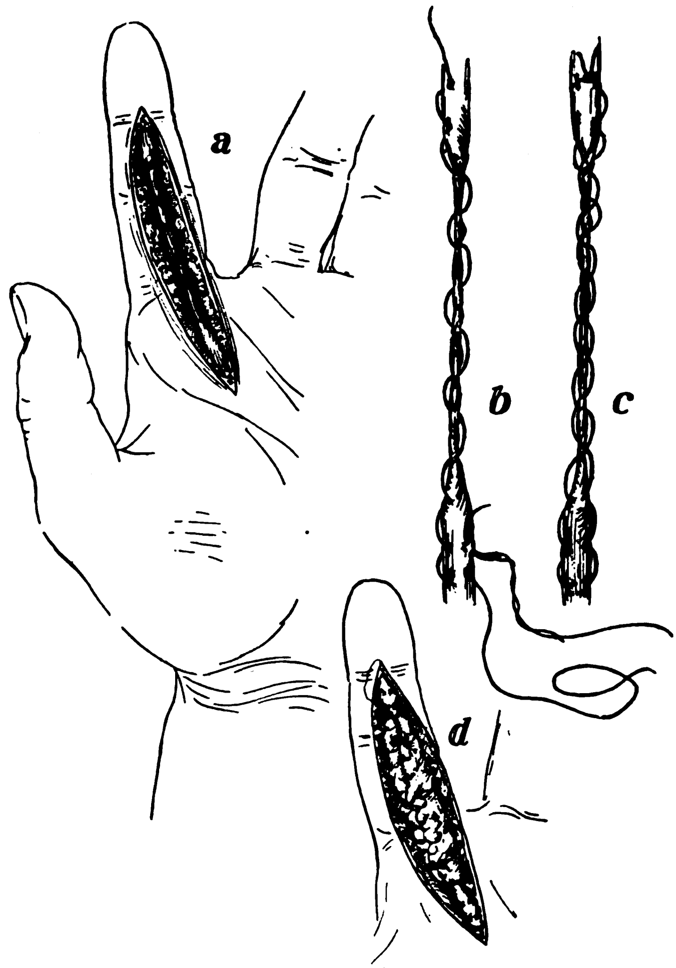


FIG. 263. RESTORATION OF TENDON BY USE OF SILK WITH FAT TRANSPLANT ABOUT IT. Both the flexor sublimis and the flexor profundus were lost. Restoration of flexor sublimis alone. See Fig. 264. (*Kanavel.*)

It is not used for simple division, as one of the methods recommended above will suffice for that. When, however, there is a considerable gap, Dawbarn cuts down upon the flexor sheath well above the seat of division, exposes the flexor sublimis and cuts from it by an oblique section a sufficient amount of tendon to fill the gap below. This portion is then seized with forceps from the wound below and is pulled down into the gap between the two ends of the flexor profundus; into this gap it is sutured after the divided ends of the profundus have been cut obliquely to receive

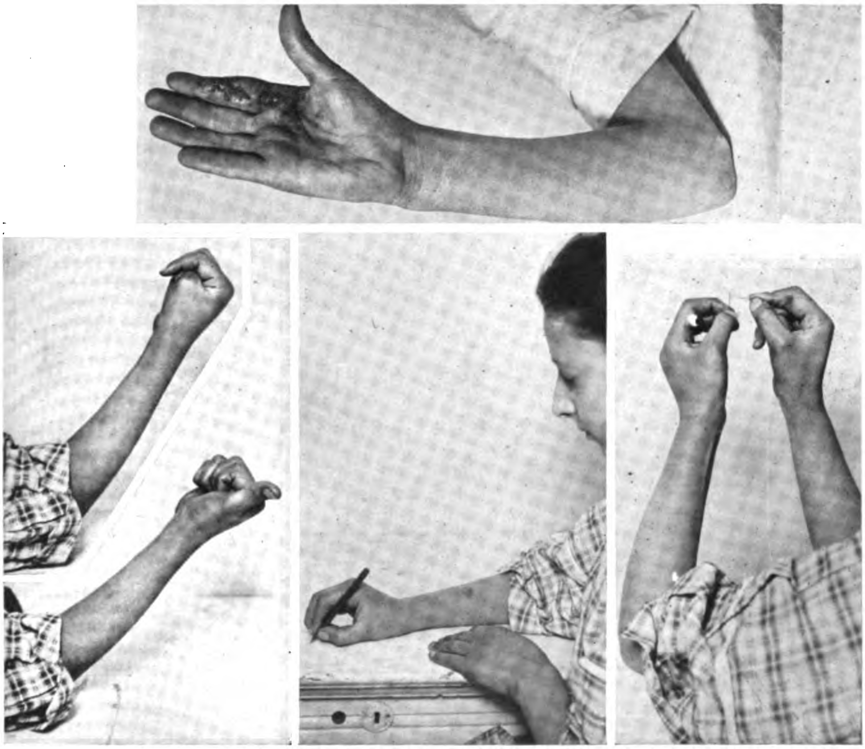


FIG. 264. SHOWS RESULT AFTER SOME MONTHS. Photograph of hand in which there was a loss of the flexor sublimis and flexor profundus tendon. Upper figure represents finger before operation. The other photograph shows various functions that can be performed by patient with finger. See Fig. 263. (*Kanavel.*)

it. The patient thus has a complete flexor profundus tendon whilst the flexor sublimis is sacrificed (see Fig. 267).

(6) *Reconstruction of tendons.* When there has been a complete destruction of tendons various methods have been used to replace them, including the use of silk, catgut, fascia lata, etc.

Fascia lata in strips of suitable size may be sutured in position to take the place of tendons, particularly if they pass through fatty subcutaneous tissue. Where they do not, the best procedure consists in transplanting a fair amount of adipose tissue with the fascia lata or, better yet, making a tube of fascia lata with fat attached to its surface and suturing the two cut ends of the tendon in either end of the tube. The latter method has been followed by good results.

Fig. 265. Restoration of Extensor Longus Pollicis by Silk with Fat Transplant about it. Over two inches of tendon were lost. See Fig. 266. (*Kanavel.*)

Kanavel has reported excellent results by the use of the silk and free transplants of fat. Silk alone in a loose subcutaneous tissue or fatty subcutaneous tissue will end in excellent tendon restoration or function.

Where conditions are not ideal, as in the hand, Kanavel has run strands of silk between the separated ends of the tendon and wrapped this in a

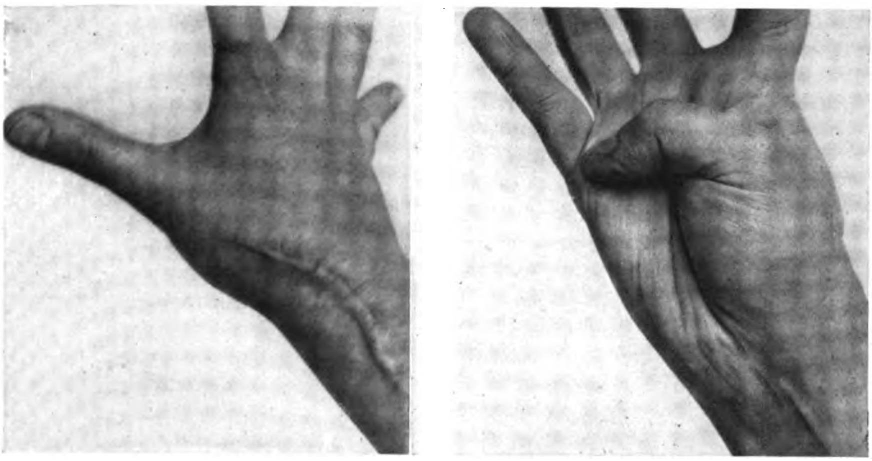


FIG. 266. PHOTOGRAPH SHOWS VARIOUS MOTIONS POSSIBLE WITH RESTORED TENDON AS SHOWN IN FIG. 265. Complete function of all phalanges is present. (*Kanavel.*)

free transplant of fat, the fat being sufficient to envelop the silk completely. The photographs and drawings show the technique and the results in clinical cases (Figs. 263, 264, 265, 266).

TENDON-SHORTENING

Indications. A tendon may require to be shortened in cases of paralysis where there is some slight contractile power left in the affected muscle and it is desired to bring it back to its normal length as soon as possible. It is called for most frequently in cases of talipes calcaneus.

Methods. There are three chief methods by which a tendon may be shortened:—

(1) A portion may be excised and the divided ends sutured together.

(2) The tendon may be detached from its insertion, a portion removed, and the tendon re-inserted, or

(3) The insertion of the tendon may be shifted bodily.

The second of these methods is probably the most satisfactory, as it is easier to secure a firm fresh attachment of the tendon to bone than it is to get satisfactory bony union after shifting the attachment of the tendon bodily, as is done, for instance, by sawing off the insertion of the tendo Achillis into the os calcis and reuniting it to the bone lower down. These are clumsy and difficult operations, whereas it is quite easy to detach the tendon from its insertion, cut off the requisite length, and re-attach it. The attachment may be done in any way that seems suit-

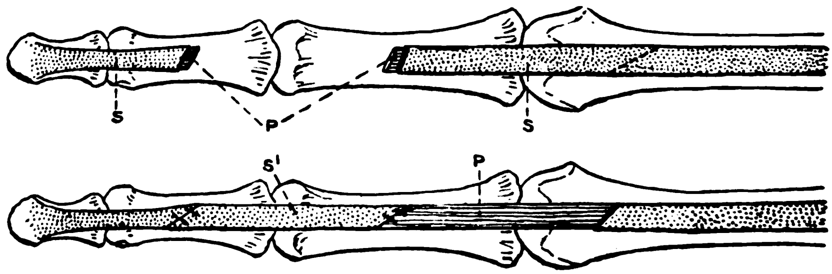


FIG. 267. AUTOPLASTIC TENDON-GRAFTING. This is Dawbarn's method. The flexor profundus, P, is repaired by means of a portion of the flexor sublimis, S.

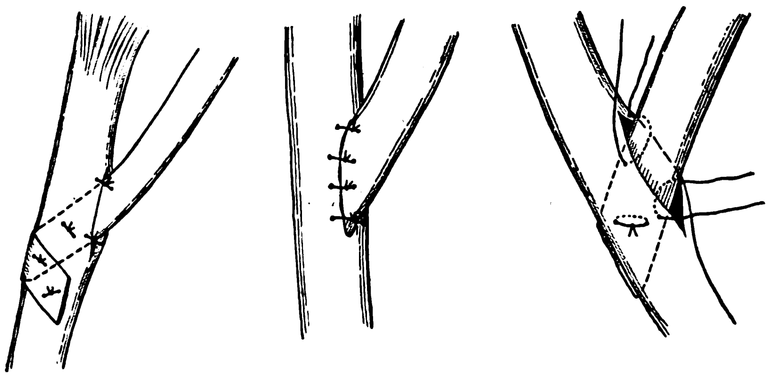
able to the operator. When a very firm hold is required, a hole may be bored in the bone, and a stout silk suture passed through this and made to fix the tendon. The limb must be kept in the fully corrected position for at least six weeks afterwards, as otherwise there is a risk of the union stretching. The nutrition is generally poor in these cases.

TENDON-TRANSPLANTATION AND TENDON-GRAFTING

Although tendon-transplantation and tendon-grafting differ in technique, they are only different methods of making a sound muscle discharge the functions of a paralysed one. Tendon-transplantation in the strict sense of the term means transference of the insertion of a tendon from one bony point to another, while tendon-grafting implies the implantation of one tendon into another. Each method has its sphere of usefulness, but the two are often combined in the same case.

True tendon-grafting may be of two kinds. In the first, the tendon of a paralysed muscle is cut across and the tendon of an unparalysed one is similarly treated. The proximal end of the tendon of the unparalysed muscle is then attached to the distal end of the tendon of the paralysed one. In the second case the tendon of the paralysed muscle is divided as before and its distal end is implanted into the tendon of an unparalysed muscle or is joined to a slip from that structure. Occasionally lateral implantations of the two tendons without division may be employed (see Fig. 269).

Indications. The assumption of the functions of a paralysed muscle by a healthy unparalysed one finds its widest application in cases of infantile paralysis. It is most useful in paralytic talipes, but it may be employed with advantage in paralysis affecting the knee, the elbow, or the shoulder. It is often combined with arthrodesis, or the artificial production of an ankylosed joint, and, in connexion with this operation, it may give most useful results. Thus, a child who has a flail-like lower extremity from paralysis of most of the muscles moving the knee and the ankle may get quite a useful limb after the production of a stiff joint in one of these articulations and the judicious application of tendon-grafting to the muscles moving the other; this



A B C

Fig. 268. Implantation of Tendons. A shows the firmest hold that can be obtained. One tendon is split and the other is passed through the slit and wrapped round it. B is simple attachment—a bad way unless the tendons are too short to allow of any other procedure. C is the ordinary implantation of the divided end into a split tendon.

will enable movements of the latter to be performed well enough for the patient to get about with a stick or even without any artificial aid.

Points to be observed in the operation. In order to obtain the best results certain points should be attended to.

(1) The operation should be performed as soon as possible after the paralysis has come to a standstill and the surgeon is able to determine clearly how much healthy muscular tissue is left in the muscles concerned.

(2) Each individual muscle should be tested carefully and its exact contractile power ascertained, as it is important to choose for the purpose of anastomosis those muscles which can act with the greatest power and at the least mechanical disadvantage. Thus, for instance, it is better to make the tibialis anticus replace the extensor hallucis longus

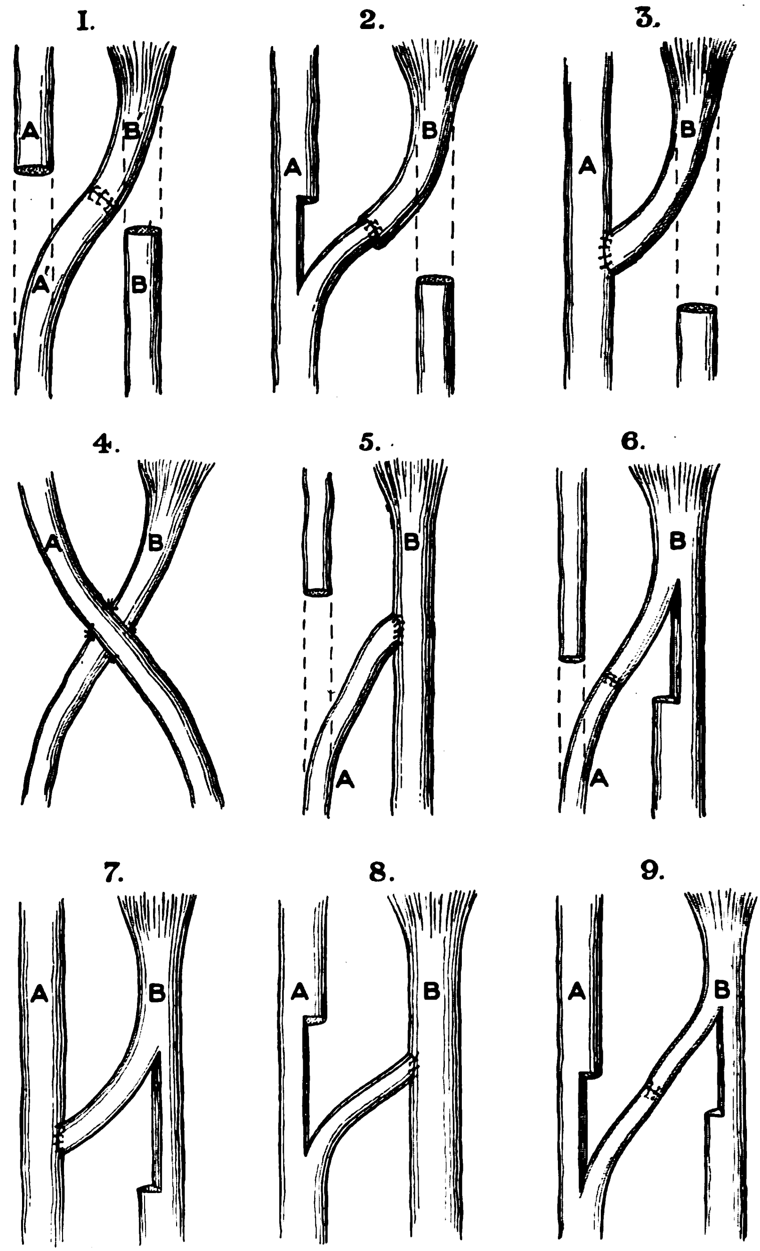


FIG. 269. VARIOUS METHODS OF TENDON-GRAFTING. In each case B is the sound muscle, A the paralysed one. The first three diagrams are the methods in which the sound tendon is divided prior to anastomosis. The last three are those in which neither tendon is divided, as is also 4. In the two remaining figures. 5 and 6, the paralysed muscle has its tendon divided but not the sound one; this is a very favourite method.

or the extensor digitorum longus rather than to bring the tibialis posticus or one of the peronei tendons around the malleolus in order to anastomose it with either of these tendons. It is, however, possible to bring tendons around the malleoli in this fashion if necessary, but this should be avoided if possible, as greater care is required in the after-treatment in order to maintain the mobility.

(3) A very firm anastomosis should be made; when possible, it is best to split one tendon and pass the other through it. This union may be still further strengthened by wrapping one tendon around the other in the manner shown in Fig. 268, A. A weak union is apt to stretch or to tear out.

(4) Whenever possible, muscles should be employed that have the same nerve-supply as the affected one. That is to say, a flexor tendon should be grafted on to a flexor muscle and an extensor tendon to an extensor muscle. This, however, is not absolutely necessary. A flexor muscle may, for instance, be united to an extensor tendon, and in course of time and by a process of education the functions of the paralysed muscle are assumed by the sound one; that is to say, a flexor muscle now produces extension. When this is done, however, complete division of the grafting and grafted tendons must be employed; if the method of uniting the two by a lateral anastomosis or by implanting the distal end of the paralysed tendon into a slip derived from a healthy one be employed (see Fig. 269) the functions of the muscle concerned will be dual and the two functions will be antagonistic and simultaneous in point of time.

(5) It is not always necessary to unite the healthy tendon to the paralysed one. The tendon chosen may be cut across and a new attachment made directly to bone in any spot at which the surgeon thinks the muscle is likely to act at the greatest mechanical advantage. For instance, the tibialis anticus or the extensor longus hallucis can be attached to the outer border of the foot so that a varus position may be remedied thereby. The tendon may be attached to bone at any desired spot by suturing it with silk passed through a hole bored in the bone. The union may be strengthened by catgut sutures passing between the tendon and the adjacent soft parts.

(6) Whatever the method adopted, matters must be so arranged that the foot is in its normal position when the tendon is united and there is neither undue tension nor undue slackness in the anastomosed structures. Care must also be taken, both at the end of the operation and throughout the after-treatment, to see that there is no undue strain thrown upon the anastomosis.

(7) Strict asepsis must be observed throughout, as suppuration is

fatal to success. It is important to tie all bleeding points and make sure that the wound is dry before it is finally closed.

Operation. No definite steps can be laid down for the operation as the cases vary so widely. The surgeon will carefully examine the limb, will ascertain which muscles are paralysed and which are healthy, will choose the best available muscle for his purpose, and will then graft it on to the affected tendon or tendons by one of the methods described for tendon suture (see Fig. 269). It may be necessary to make a wide dissection in order to do this, and in all cases it is best to expose the tendons by raising small flaps, so that the seat of anastomosis shall be away from the line of union in the soft parts; this increases the chances of perfect movement subsequently.

When a tendon has to be anastomosed to another at a considerable distance, the raising of a single flap large enough to expose both tendons would entail division of many soft structures, such as veins and nerves; in such a case it is better to make a separate incision over each tendon, and, after preparing and dividing both, to pull the distal end of the one through to the proximal end of the other with forceps passed through the subcutaneous tissue from one incision to the other. The passage of tendons through these new subcutaneous paths does not interfere materially with their mobility.

After-treatment. A great deal depends on successful after-treatment, as all the benefit that can be derived from tendon-grafting may be lost if the limb be put up with the newly-grafted tendon on the stretch, so that the muscle is at a mechanical disadvantage. It should be fixed in a slightly over-corrected position in plaster of Paris or some similar immovable apparatus, where it should be kept for a month or six weeks so as to allow union to take place undisturbed. At the end of that time, the patient may be fitted with a light orthopedic apparatus which does not allow the corrected position to be passed and the faulty one assumed. This should be worn for three to twelve months according to the progress made, and during this time massage and selected active and passive exercises designed to strengthen the affected muscles should be practised vigorously. The essential point for success in this method is to see that the limb is never allowed to fall into its old position of deformity, which it will readily do as long as the union is weak or the muscle is not powerful enough to do its work unless strengthened by suitable apparatus. This precaution is especially necessary when a weak muscle has been made to take the place of what should be a powerful one. It is only by means of cautiously graduated exercises increasing in strength that the muscle is made to hypertrophy so as to fulfil its new functions with any degree of success. It is disregard of this precaution that so often leads to the disappointing results that are occasionally experienced in connexion with tendon-grafting.

Results. After examining a considerable number of cases operated upon by this method I feel that one may fairly come to the conclusion that the method is of considerable value. It must not be expected that it will cure or even greatly improve every case, but when it is judiciously employed and the after-treatment is carefully carried out, there will be some definite improvement in nearly every case for which it is suitable; in some cases, chiefly those of minor degrees of paralysis occurring in isolated but important muscles, the improvement may be most striking. Operation, however, should be performed before the limb has got into an exaggerated condition of deformity if good results are to be looked for with any confidence. Those advanced cases of talipes marked by extensive alterations in the shape of the bones are practically beyond its range of usefulness.

CHAPTER III

OPERATIONS UPON TENDON SHEATHS AND BURSÆ

It is occasionally necessary to perform operations upon tendon sheaths apart from operations upon the tendons themselves, and as these nearly always take the form of removal of the synovial sheath it will be necessary to say a few words about them.

EXCISION OF THE SHEATH OF A TENDON

Indications. The so-called compound ganglion of the wrist, which is really a tuberculous teno-synovitis, will call for excision of the common sheath of the flexor tendons. Tuberculous teno-synovitis is fairly common either as a primary affection, as in the case of the so-called compound ganglion of the wrist, or secondary to disease of the joint, as, for example, teno-synovitis about the ankle and wrist secondary to disease of those articulations.

Operation. The steps of the operation required cannot be given with any exactitude, as they must vary with the particular tendon that is the subject of operation. Certain points, however, should be borne in mind if this operation is to be done successfully, and, as the success that attends a well-planned and properly executed excision of tuberculous tendon sheaths is most gratifying both as regards the extirpation of disease and the restoration of function, it is well to enumerate them in detail.

(*a*) The area to be operated upon should be exposed freely so that the excision may embrace the entire affected area.

(*b*) The flap method should be employed where possible, as it avoids a linear cicatrix directly over the denuded tendon and thereby diminishes the chance of adhesion of the two structures and increases the chance of complete restoration of function.

(*c*) The diseased synovial sheath should be removed entirely with knife or scissors; it should be clipped away cleanly, and no attempt should be made to scrape it away with a sharp spoon or any other clumsy instrument.

(*d*) The excision should be commenced by defining the synovial layer which lines the tendon sheath. This should be dissected up as far round as possible from one side of the incision into the sheath, and a similar procedure is then carried out from the other side until the entire synovial lining has been removed, the tendon being hooked up out of its bed while this is done.

(*e*) After complete removal of the lining membrane of the sheath the tendon itself must be examined, and if it has undergone any definite changes the synovial layer covering it must be dissected away as thoroughly as possible. This, of course, is a matter of difficulty owing to the extreme thinness of the synovial covering in places, and in cases of doubt it is best to err on the side of taking away too much rather than too little, and to remove a slice from the surface of the tendon with a sharp knife so as to make sure that all the disease has been removed. Particular care is required in the upper part where the tendon joins the muscle to see that all the affected synovial covering is removed. If tuberculous deposits be seen on the surface of the muscle itself that structure should be removed widely, as when tubercle finds its way into muscle it spreads rapidly and the chance of recurrence is greatly increased.

Every tendon that requires treatment in this way must be gone over in turn thoroughly. The operation is tedious, but if it be done in this systematic manner the results are remarkably good. The wound is rendered perfectly dry before it is closed, care being taken to ligature all bleeding vessels. The tendons are then laid down in their denuded sheaths and the latter may be sutured over them in some cases. The skin flap is united without a drainage tube and the limb is put up in a position in which the affected muscles are relaxed; that is to say, if the operation has been performed upon the extensor tendons of the hand the hand is put up fully extended, while if the operation has been on the palm the hand is flexed. The object of this is to render it easy to break down any adhesions that may occur after the operation.

Anatomical considerations must dictate the particular form that the incisions shall take. Thus, for instance, if the entire back of the hand has to be operated upon it will be well to raise two separate flaps so as to avoid dividing too much of the cutaneous nerve-supply of the hand. Similarly, when operating upon the flexor tendons the operation will probably be done through a series of incisions, as it is important to avoid injury to the median nerve and its branches in the hand. The anterior annular (laciniate) ligament, however, may be cut through without hesitation in order to facilitate access to the synovial sheath beneath.

Results. These are remarkable in their completeness, if the operation has been thorough and the wound has remained aseptic. All the tendons on the back or the front of the hand may be treated in the same manner and the patient nevertheless preserve perfect use of the fingers. One patient from whom I removed the synovial sheaths of all the flexor tendons from the first inter-phalangeal joint to above the great palmar bursa in the right hand was enabled to earn her living by teaching the violin; and another, upon whom a similar operation was performed on all the tendons on the back of the hand, plays the piano without the least inconvenience.

OPERATIONS UPON BURSÆ

These require no special description, as the operations are simple dissections, the only point of interest being the various incisions necessary in the various situations. Bursæ should always be dissected cleanly out and, as a rule, the incision will be directly over the swelling. In the case of the prepatellar bursa, however, it is well to raise a flap over the bursa, with its convexity upwards, reaching just beyond the upper limit of the swelling. This is done because the scar would be exposed to pressure were it either a median vertical one or a flap with its convexity downwards, as in kneeling the tubercle of the tibia and the adjacent part of the ligamentum patellæ come into contact with the ground.

SUBACROMIAL BURSITIS

In subacute or adherent subacromial bursitis a longitudinal incision three inches long is made extending from the tip of the acromion process over the bicipital groove, splitting the deltoid. The roof of the bursa is thus exposed just beneath the muscle and is picked up with tissue forceps and nicked. The incision in the bursa is then extended and the interior of the sac explored. Adhesions are then divided or the deltoid portion excised. It is impossible to excise the subacromial portion owing to its inaccessible position. A good exposure of the bursa may be obtained by producing sudden strong traction on the arm after the bursa has been opened, thus separating the tuberosity from the acromion. The bursa is loosened at its periphery down to its attachment to the tuberosity and subscapularis tendon. The bursa is then detached by sharp dissection and peeled upward to the point where it passes under the tip of the acromion. The skin is then closed with silkworm-gut.

In the chronic type where no adhesions have formed or, if formed, have been stretched, it is not infrequent to have calcareous or osseous deposits, or folded and thickened ridges of the bursal sac which must be removed. The bursa is incised as in the subacute type and explored.

Deposits quite frequently are found lying beneath the floor of the bursa and attached to the underlying tendon of the subscapularis, in which position the floor of the bursa is also incised and the deposit either curetted or removed by sharp dissection. The incision in the bursa may then either be left open or closed with fine catgut suture.

SECTION VII

OPERATIONS FOR NON-TUBERCULOUS AFFECTIONS OF THE BONES

BY

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CHAPTER I

OSTEOTOMY

Indications. Osteotomy or simple division of a bone may be required for various purposes.

(i) The most common condition is deformity due to *rickets*. This generally takes the form of a curve of the femur or the tibia, giving rise to genu valgum or genu varum. Some of the more complicated rickety deformities of the lower extremity may also require an osteotomy.

(ii) Osteotomy is often done for the rectification of deformity due to *ankylosis* in a faulty position following hip disease. Here the osteotomy may be through the neck of the bone or in the sub-trochanteric region.

(iii) Osteotomy of the femur has been recommended and successfully practised for the treatment of *coxa vara*. The operation is rarely necessary, however, as simple mechanical means will suffice for a cure in the great majority of cases.

(iv) Osteotomy either of the femur or of the tibia and fibula has been practised by some surgeons, particularly in America, for the relief of the inveterate inward rotation associated with bad cases of congenital *talipes varus*.

(v) Occasionally a simple osteotomy will suffice to rectify *mal-union after a fracture*. As a rule, however, either simple re-fracture suffices, or a more elaborate operation followed by the use of some means of mechanical fixation is necessary.

Operation. Concerning the operation of osteotomy in general, little need be said. The division of the bone may be done with a saw or a chisel.

Subcutaneous osteotomy. A clean cut is made down to the bone with a stout knife parallel to its long axis. The soft parts are cleared from the surface of the bone by a raspatory, so that the saw can be passed down to the bone flatwise along it. The cutting edge is then turned towards the bone, which is divided by short rapid strokes. The bone may be sawn through entirely, or it may be fractured after the major portion has been divided by the saw. The osteotome is used in a similar manner.

Done in this way, the operation is almost subcutaneous. It can be made entirely subcutaneous if desired, but the above plan is to be recommended whenever there is any important structure, such as a large vessel or nerve in the immediate vicinity of the bone to be divided. It is better to make a wound large enough to expose the bone; then the surgeon can see that he introduces the instrument between the bone and the soft structures.

Open osteotomy. When osteotomy is done through an open incision any suitable kind of saw or chisel may be employed, and the bone ends either remain in position spontaneously or are maintained by some form of fixation apparatus (see p. 705). As a rule the latter is not required for rickety deformities, but it may be called for in the other conditions requiring osteotomy. This form of osteotomy may be divided into two groups, which may be called *linear* and *cuneiform* osteotomy, according as a simple division or a removal of a wedge of bone is practised.

There are certain special forms of osteotomy that call for description; the chief ones are described in the following pages.

MACEWEN'S SUPRA-CONDYLOID OSTEOTOMY

At the present time this operation holds the field for the cure of genu valgum of a certain degree of severity to the exclusion of all the older methods; no other will be, therefore, described here. It is suitable for cases of genu valgum in which the separation between the malleoli is more than three inches and a half, and in which ossification is progressing actively, so that no improvement of the deformity is likely to be brought about by splints. It is equally suitable for the adult and for the juvenile form of genu valgum, but in exaggerated cases in children it often has to be combined with osteotomy of the tibia, which is generally of the cuneiform type (see p. 677).

Operation. The knee is flexed to an angle of 135°, and a firm sand-bag is placed under its outer side, the thigh being somewhat abducted and rotated outwards. It is most important to purify the limb from mid-thigh to mid-calf and to surround the remainder of the extremity securely with sterilized cloths so that neither the surgeon's nor the assistant's hands can come into contact with unsterilized structures during the course of the operation.

An incision is made at the junction of a horizontal line drawn across the thigh a finger's breadth above the upper limit of the external condyle with a vertical one drawn nearly the same distance in front of the adductor tubercle. At this point the knife is sunk straight to the bone and in this situation is fairly sure not to divide any vessel of importance. A broad knife, such as a breast knife, makes an excellent instrument, as it need only be driven straight down to the bone and the osteotome can then be introduced flatwise along its blade until the bone is reached. The knife is then withdrawn, leaving the edge of the chisel held firmly in contact with the bone. Usually the incision through the skin is made parallel with the long axis of the limb, and therefore the osteotome has to be turned through a right angle in order to make

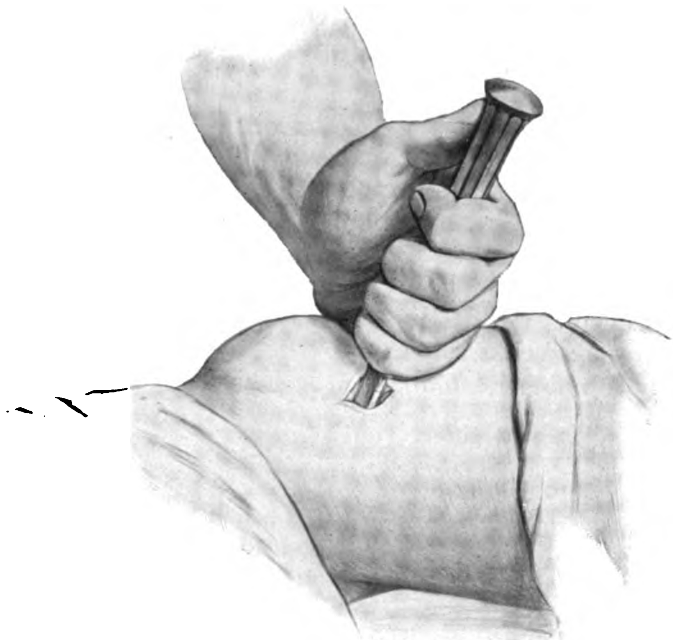


FIG. 270. METHOD OF HOLDING MACEWEN'S OSTEOTOME. If the instrument be held in this manner it is kept perfectly firm and is not likely to slip suddenly and do damage.

the section of the bone. It is grasped as shown in Fig. 270, and by means of light strokes with a mallet or hammer is made to divide the inner and posterior part of the bone first; then the osteotome is driven forwards and outwards until the outer aspect of the triangular surface of the back of the femur is reached. The compact tissue is easily recognized by its hardness, and consequently the difficulty with which the osteotome penetrates it. In children the cancellous tissue can often be divided by the mere pressure of the hand unaided by a mallet. After two-thirds or three-quarters of the thickness of the bone have been divided the remainder may be fractured. The thigh is grasped with one hand and the leg with the other and the remaining portion of bone is snapped by bending the limb sharply inwards. As soon as it is felt to give, the limb is brought into the fully corrected position. Osteotomes of different sizes may be used if desired, a smaller one being inserted to complete the division begun by the large one; few surgeons use more than one size at the present time, however, and then only in adults. The cutaneous wound is sutured and the limb is secured in the corrected position by suitable splints.

After-treatment. The limb may, if desired, be put up in plaster of Paris directly, but it is well to delay this for about a fortnight, when the sutures can be removed and any further correction that may be necessary can be made under an anæsthetic and a plaster casing applied whilst the patient is still unconscious. It is somewhat difficult to be sure of getting the limb into perfect position immediately after the operation as the bulky first dressing obliterates landmarks. In small children it may be necessary to take the bandage round the pelvis in order to get sufficient hold. The immovable apparatus should be continued until a firm union has occurred, which should be in about six weeks from the time of the operation. The patient is allowed to get about freely in another month, if firm union has occurred, and, as the operation will not have been performed until the rickety period is passing off, recurrence is not likely; should there be any fear of this, the patient must be fitted with an apparatus preventing recurrence of the deformity but allowing the free use of the knee-joint.

Difficulties and dangers. A consideration of the steps of the operation might lead to the anticipation that there are many difficulties and dangers to be met with. It is extraordinary, however, to see how free it is from complications of any kind, and many surgeons have done many hundreds of these operations without a hitch of any kind. Non-union is practically unknown; the bone surfaces are broad and are never separated, probably because the division is always somewhat incomplete, the periosteum at least remaining intact at some part of the bone. Wound of the knee-joint also seems never to occur, or, if it does, to be quite harmless. Wound of the popliteal artery, which a theoretical consideration of the operation might lead one to think would be a not infrequent complication, rarely, if ever, occurs. Even free bleeding from division of any named branch is rare and is easily stopped either by pressure or, in extreme cases, by enlarging the wound. The only difficulty with which I am personally acquainted is that of not being able to re-introduce the osteotome into the line of bone section after having withdrawn it in order to see whether the bone can be fractured. The best way to avoid this is to divide the bone until a very slight pressure will fracture it; this is only learnt by experience. It can also be avoided by imparting to the osteotome movements in the vertical direction, so as to widen the groove that it makes in the bone; this prevents locking and also facilitates the identification of the groove when the instrument has been removed.

Results. The results of this operation are most satisfactory. It is of universal application and few similar operations give such admirable results with such a minimum of risk. It is a perfectly satisfactory treatment for genu valgum of a moderate degree. In the more extreme forms cuneiform osteotomy of the tibia should be either substituted for or combined with it.

OSTEOTOMY OF THE TIBIA

Indications. (i) Division of the tibia is usually done for deformities due to rickets.

(ii) Badly united fractures with serious deformity resulting in impaired locomotion may call for osteotomy; but this will generally be preliminary to mechanical fixation of the fragments. It is not infrequently required for fractures in the region of the ankle-joint where the direction of the lower fragment is so altered that the body-weight is transmitted at a mechanical disadvantage.

(iii) Osteotomy of the tibia and fibula has been practised for the cure of the persistent inward rotation that accompanies bad talipes equino-varus.

The operation may be done in several ways and in various situations. Thus it may take the form of linear or cuneiform osteotomy, either of which may be performed in any part of the bones, the upper and lower ends being the most common situations—in the upper end for genu valgum, in the lower for the bowing forward of the tibia so common in rickets. The section of the bone may be made in any direction; as a rule a cuneiform osteotomy by the open method is done for rickety deformities, as the surgeon is thereby able to do very accurate work.

Operation. When cuneiform osteotomy is to be done, the surgeon, having settled the spot at which he will divide the bone, raises a flap over it so that the cicatrix in the skin shall not lie over the bone section. The spot usually chosen for osteotomy of the tibia in genu valgum is just below the upper epiphyseal line of the tibia, while that for the antero-posterior curvature of the lower end of the bone is well above the lower epiphyseal line; in the latter case the flap is best raised by means of a crescentic incision with its convexity inwards and its extremity lying just over the anterior border of the bone. The flap is raised and the subcutaneous surface of the tibia is exposed over an area corresponding to the base of the wedge that is to be removed from it. The wedge is now marked out either with a few strokes of an osteotome, or with an osteotomy saw; it is most conducive to neat work to make the preliminary groove with an osteotome, as by it the shape of the wedge can be marked out very accurately and the inclination of its sides can be determined better than by the saw. The actual division of the bone is best effected, however, by the latter instrument, which is introduced into the groove thus made, and the wedge of bone cut cleanly out, the soft parts being meanwhile protected by inserting thin spatulæ between them and the bone. In making the bone section, care must be taken not to damage the anterior tibial artery or nerve, which lie upon the interosseous membrane and are very easily wounded. If there be any doubt as to the exact amount of bone that requires to be removed it is well to take out a smaller wedge than is necessary, as it is easy to remove more bone with a sharp chisel, or to alter the angles of the wedge. Throughout the sawing and chiselling manipulations the limb should be laid on its outer side upon a firm sand-bag.

When the wedge has been removed, the fractured surfaces are brought into apposition, and this should rectify the deformity. In an adult the fibula must be divided before this can be done, and this can be accomplished through a small vertical incision below the neck of the bone, which is bared with a rugine and either nipped across with bone forceps or partly sawn through with an Adams's osteotomy saw, and then fractured by bringing the limb into position. In young children, however, the fibula is so elastic that it offers no obstacle to the reduction of the deformity, and even in older children, although this elasticity may be troublesome, it can be overcome by over-correcting the deformity and creating a greenstick fracture. Bleeding is rarely troublesome although there may be free oozing from the medulla; this, however, always stops as the two bone surfaces are squeezed together when the deformity is rectified.

It is often difficult to remove the exact amount of bone necessary to get complete reduction of the deformity at the first attempt. The surgeon should not be satisfied with the result, however, until he has obtained rectification of the deformity and accurate coaptation of the fractured surfaces; for the finishing touches a sharp chisel is invaluable. When the bone surfaces are brought together, it is important to see that no flap of periosteum becomes turned in over the ends of the bone. No fixation apparatus is ever necessary for rickety cases. Operations performed for mal-united fractures are separately dealt with (see p. 722). All bleeding should be carefully arrested and the wound sutured without a drainage tube. Only a small amount of dressing is applied, so that the surgeon is able to see the outline of the limb, and can therefore apply the retentive apparatus more accurately than if the leg were enveloped in a large mass of dressing. The simplest plan of putting up these cases is to apply a light plaster of Paris casing, fixing the knee and ankle. This will require to be taken off when the stitches are removed; some form of Croft's removable casing answers admirably.

The other method is to secure the limb in splints, which may either consist of a back and two side splints with a foot-piece at right angles, or a roll of Gooch's splinting in which the limb is so fixed with pads that the corrected position is properly maintained. Of these methods the former is the more suitable for all cases in which the surgeon is sure of his asepsis, and the patient is old enough not to soil the casing with urine. The other method is useful in quite young children, as soiling of the apparatus is easily detected and can be prevented from doing harm by changing the dressings.

After-treatment. The first dressing is left untouched for a fortnight, when an anæsthetic is administered, the sutures are removed, and the limb put up in a plaster of Paris casing, which fixes the knee and ankle joints. This is kept on for a month, when the bone should have united. It will, however, be necessary to keep the child off his feet for a period of nearly two or three months longer, unless the case be one in which all signs of rickets have passed off and the bones have undergone full ossification.

SUB-TROCHANTERIC OSTEOTOMY OF THE FEMUR

Osteotomy of the neck of the femur and trans-trochanteric osteotomy are described separately (see Vol. II).

Indications. Sub-trochanteric osteotomy of the femur may be done for:—

(i) *Deformity following ankylosis in hip disease.* Division of the neck of the femur or of the great trochanter is theoretically a better method of relieving this condition than is division of the shaft of the femur below the trochanters, and should be preferred whenever it is feasible. There are many cases, however, which can now be detected by the X-rays, in which the fusion of the femur to the pelvis is so extensive that division of the bone below the trochanters is a simpler and more satisfactory method.

(ii) Sub-trochanteric division has been employed for the cure of *coxa vara,* the object being to rotate the shaft of the femur round its long axis and so overcome the eversion of the foot, the two fragments being united by some suitable mechanical apparatus. This operation, however, is not likely to find extended favour for this purpose. The risk of deformity or of non-union can never be ignored, while no operation is ever called for in young children, and in adults cuneiform osteotomy of the neck of the femur is preferable.

Operation. This is quite simple. The level of the lesser trochanter is about two inches below the top of the greater, and therefore the osteotome should be applied about half an inch or more below this spot. A vertical incision about an inch and a half long is made over the outer surface of the femur with its centre opposite the above point and carried down to the bone. The osteotome is then introduced flatwise along the blade of the knife, turned at right angles to the shaft of the bone, and made to cut across horizontally from the outer to the inner side, dividing first the compact bone of the front and outer aspects of the shaft and then that in the neighbourhood of the linea aspera. When two-thirds of the bone have been divided, the remainder should be snapped by carrying the limb inwards until it is felt to crack; the deformity is then rectified, and the limb is put up in an immovable apparatus after the wound has been sutured. The best apparatus is that recommended for use after operations on the neck of the femur.

CHAPTER II

OPERATIONS FOR OSTEOMYELITIS AND ITS SEQUELÆ

FOR ACUTE INFECTIVE OSTEOMYLITIS

Operation. As soon as the diagnosis is established, a very free incision must be made over the affected bone under full anæsthesia. The periosteum must be divided freely, the incision reaching well above and below the affected area; it is of the highest importance that it should be free enough to allow all the pus to escape. When the pus between the periosteum and the bone has been evacuated careful examination must be made to see whether the abscess has burrowed round the bone laterally, and, should this be the case, the periosteum is divided transversely also, or suitable counter-openings are made to establish free drainage. It is not sufficient to make a free opening anteriorly, as pus may continue to burrow around the bone in spite of this.

In all cases of acute infective osteomyelitis it is always well to open the medulla when any quantity of pus is found beneath the periosteum, as the disease frequently commences in the centre of the bone. A good plan is to remove a circle of the compact tissue of the bone with a half-inch trephine, so as to permit a satisfactory inspection of the medullary canal. If no pus be found, the cavity may be swabbed over with a saturated solution of chloride of zinc and lightly packed with iodoformed gauze; then there will be scarcely any risk of the infection spreading from the surface to the deeper parts.

If, however, pus be present in the medulla, the whole of the cavity containing it should be freely exposed by cutting away all the bone over the suppurating area with a gouge, trephine, or chisel according to the taste of the operator. The cavity is thus laid bare from end to end and is lightly packed with iodoformed gauze; it will drain satisfactorily if the packing be only loosely applied. It is not advisable to use a sharp spoon to remove the suppurating medulla, as is often done; the procedure is not likely to eradicate the entire diseased area, and only serves to destroy any osteogenetic portion of the medulla that has so far escaped destruction by the suppurative inflammation. So long as the pus is not under tension, it will drain satisfactorily, and the least damage results if simple but ample drainage be established.

If the suppuration in the medulla extends up into the epiphysis, the cavity in which the pus lies must be opened up equally freely, and that portion of the epiphysis overlying the abscess cavity must be sacrificed without hesitation.

At the original operation, no attempt should be made to remove bone for any other purpose than mere drainage, except in the rare cases in which the shaft of the bone is completely detached both from the epiphyseal lines above and below and from the periosteum circumferentially. This involves the death of the entire shaft of the bone, and the dead diaphysis can be lifted out from its periosteal bed with advantage, as regeneration of the bone will then occur better than if it were left to form a sequestrum. Failing this, however, no attempt should be made to remove bone except for the purpose of drainage, as it is impossible to tell at the time of the operation how much bone has been destroyed; this important point can only be ascertained by waiting.

After-treatment. The limb should be kept at rest upon a splint, and should be syringed out daily, or oftener according to the amount of discharge, with peroxide of hydrogen solution (ten volumes per cent.), after which it may be lightly stuffed with iodoformed gauze. The formation of healthy granulation should be promoted by all means possible. For this purpose light packing is better than firmly stuffing the wound.

SEQUESTROTOMY

Indications. Sequestrotomy may be required for the relief of several conditions; thus:—

(i) It may be necessary for the removal of a sequestrum resulting from acute infective osteomyelitis

(ii) After traumatic septic necrosis a sequestrum may have to be removed, for instance, from an amputation stump or from a compound fracture.

(iii) In 'quiet' necrosis sequestrotomy will be necessary.

(iv) Syphilitic necrosis is often followed by the formation of a large sequestrum which demands removal by surgical means.

(v) In tuberculous necrosis a sequestrum, although occasionally capable of absorption, should be removed whenever its presence is diagnosed, as this greatly increases the chances of a cure and hastens recovery.

The steps of the operation for removal of a sequestrum vary according to the nature of the disease that has led to the production of the sequestrum that it is designed to remove, and accordingly three methods will be described:—

(*a*) For removal of a sequestrum following infective osteomyelitis.

(*b*) For removal of a deep-seated sequestrum resulting from 'quiet' necrosis or syphilis.

(*c*) For removal of a tuberculous sequestrum.

REMOVAL OF A SEQUESTRUM FOLLOWING ACUTE INFECTIVE OSTEOMYELITIS

In these cases the most important question is *the period at which to operate*. It is essential that the whole necrotic area should be removed at the operation and that no sequestra should be left behind to prolong healing and necessitate a second operation; therefore, operation should not be practised until the surgeon is able to ascertain fairly accurately how much of the bone is dead and requires removal. Quite apart from the inadvisability of prolonged waiting from the point of view of the patient, who is confined to bed meanwhile and has to have frequent dressings, it is very important to intervene as early as possible, because the prospects of regeneration of new bone to take the place of the sequestrum are directly proportionate to the shortness of time that has elapsed between the occurrence of the necrosis and the removal of the sequestrum. The reason of this is that when necrosis occurs the periosteum is stripped from the bone by the inflammatory exudation and after a short time becomes covered with granulation tissue which has a high osteogenetic power. If this osteogenetic function be allowed time to come into full play it surrounds the necrosed bone with a rigid sheath of new bone of a more or less permanent character. Unlike normal bone, growth can only take place from the periosteal surface of this newly-formed bone, and no endosteal increase is possible; therefore the cavity in the ensheathing layer of bone in which the sequestrum lies does not fill up from the interior.

Operation in recent cases. From these considerations it follows that it is of great practical importance to remove the necrosed bone before it has become a true sequestrum, that is to say, before the dead portion has become locked in and buried by new periosteal bone. If this can be done while the periosteum is still soft and plastic, that structure can be made to approximate itself to the remaining normal bone, with which it becomes fused, so that no cavity is left. The practical result to be deduced from this, therefore, is that in every case a sequestrotomy should be done at the earliest moment at which it is possible to tell how much of the bone is dead.

This power of regeneration is very remarkable, and extraordinarily good results have followed removal of the entire shaft of the tibia for acute infective osteomyelitis at the time of the original operation. The periosteal walls fall together, the small cavity thus left is filled with osteogenetic granulations, and a new tibia, which in the course of time becomes sound and almost of the normal size, takes the place of the old one. This is in marked contrast to the hopelessly unsatisfactory results that often follow removal of a sequestrum for the same disease when the dead bone has been allowed to remain *in situ* bathed in foul pus for many weeks or months; even after removal of the sequestrum in these cases a foul discharging cavity may persist for the remainder of the patient's life.

The period at which the demarcation between the living and the dead bone can be made out clearly will vary with the bone affected. Thus it may be possible to be certain upon this point in some cases within a month, while it takes more than two months in other cases—such, for instance, as the femur. The exact time for operating is rather difficult to tell, but the most careful efforts must be made to ascertain it. An X-ray photograph may give valuable help in defining the limits of the necrotic area, but the most important test is to determine the period at which the periosteum begins to undergo ossification, as it is then sufficiently plastic to be moulded into position. It may be taken as a safe rule that ossification in the periosteum does not advance far until the line of demarcation between the living and dead bone is fairly established. The onset of ossification may be ascertained by feeling the small spicules of bone in the vascular periosteum; these may occasionally be felt with the finger, or a probe or needle may be made to rub against the bone spicules, or some of them may be actually scraped away with a sharp spoon and examined microscopically. It cannot be too strongly insisted that every care should be taken to determine the time at which the operation should be performed, as the patient's future comfort may depend largely upon the right time being chosen.

Operation. The whole of the affected area must be exposed freely by any incision or incisions that seem most suitable for the purpose. Any sinuses present should be included in the incision if possible, their orifices being surrounded by an elliptical incision so that they can be removed completely. The periosteum is divided throughout the length of the incision and turned back carefully with a rugine (see Fig. 271). All unnecessary violence in reflecting the periosteum must be avoided, as it is upon the vitality of this structure that the chances of a successful result depend. Lateral incisions into the periosteum may be made, if necessary, so as to reflect it without undue bruising.

When the dead bone has been fully exposed in this manner it is removed by whatever method seems to be most satisfactory. If it be small and quite free it can be pulled out by necrosis forceps, otherwise a chisel or gouge may be required. If there be any doubt as to whether any portion is dead or not, it is best to remove that portion in order to make sure; it is always better to remove more than is absolutely necessary rather than too little. If necessary the whole thickness of the shaft of the bone must be taken away without the least hesitation. Excellent results have been obtained after limited resection of the whole breadth of the shaft in this way; this will not often be necessary, but it may be done fearlessly when there is a doubt as to whether the whole thickness of the shaft has perished or not.

After removal of the dead bone the cavity is flushed out so as to remove clot and to enable the operator to see whether any spicules of bone have been left behind. The wound is then irrigated with a solution of peroxide of hydrogen (ten volumes per cent.) and the two sides of the periosteal cavity are brought together as closely as the conditions will allow and, if necessary, are sutured together. Ample drainage must be provided; this is a point of the highest importance. The limb is put

FIG. 271. FARABEUF'S RUGINES. The ends, which are straight or curved, are strong and as sharp as chisels. They can be used with great precision.

up in some immovable apparatus, of which the best is a splint of malleable iron secured to the limb by plaster of Paris bandages so arranged that the wound is fully exposed and accessible for the purpose of dressing, without the risk of any discharge getting between the skin and the plaster and giving rise to dermatitis. The *after-treatment* is similar to that for the preceding operation.

Results. The results can be fairly described as excellent. New bone is thrown out quickly and a solid mass of periosteal bone takes the place of the dead portion; this eventually becomes moulded to the shape and size of the bone that it replaces. These really good results, however, can only be expected to occur when the affection arises in one of two parallel bones; for example, in the leg or forearm. If the whole extent of the femur or the humerus be affected there is no sound bone to act as a splint and the risk of shortening and deformity is very great. Extension would have to be used after operation, and great care taken to prevent rotation of the lower end of the bone upon the upper. It is only reasonable, therefore, to think that the best course of procedure in these cases is to wait until a sufficient splint of new periosteal bone has formed before the sequestrum is removed; the operation is described below. The risk of shortening and deformity is thereby reduced, but on the other hand the great advantage of rapid healing and reconstruction of the affected bone is greatly jeopardized.

It occasionally happens that small sequestra form again during the after-progress of these cases. This may be due to small spicules of the original sequestrum having been left behind or to the occurrence of further necrosis due to sepsis. These, however, are easily removed, especially when their presence and situation can be accurately made out by means of the X-rays.

Operation in long-standing cases. These cases are less frequently met with than they were, as early operation is now the rule; in them the sequestrum is deeply placed, being walled in on every side by masses of new bone, and lying in a cavity lined with foul granulations often riddled with sinuses. Although it may be easy enough to remove the sequestrum, the outlook is bad in the extreme, as there are few tasks in surgery harder than to bring about the closure of a large septic bone cavity. The reason for this is that the cavity possesses little or no osteogenetic power and is therefore incapable of obliterating itself by the growth of ossifying granulation tissue. The osteogenetic functions of the medulla are destroyed quite early by the septic inflammation, and no further encroachment of the healthy medulla upon the affected area can take place owing to the blockage of the medullary canal by a mass of septic granulations and ossified material. We thus get a rigid cavity incapable of spontaneous obliteration, and some special means will be necessary to effect its closure.

It will be seldom possible to raise a satisfactory flap over a bone that is the subject of long-standing septic necrosis, because the limb will be riddled with sinuses, the pus finding its way out through the so-called 'cloacæ' in the newly-formed periosteal bone and thence through the skin. The best plan is to make one or more longitudinal incisions, including in them if possible the openings of all the sinuses in the skin, the edges of which should be surrounded by elliptical incisions and removed. The incisions go down to bone throughout and the periosteum should be reflected over the entire area that the sequestrum is known to occupy. The latter is then exposed with a chisel or gouge, beginning from one of the cloacæ and working upwards and downwards until the entire sequestrum is laid bare. When the sequestrum involves nearly the whole length and thickness of the shaft of the bone, the ensheathing layer of newly-formed periosteal bone might be so damaged as to render the limb liable to fracture if sufficient bone were removed to expose the sequestrum fully. Under these circumstances it is customary to expose one-half of the sequestrum, cut it across with powerful cutting-pliers or with a Gigli's saw, and then to remove the exposed half, and afterwards pull the other half down into the trough thus left, whence it can be removed in its turn. Careful examination must be made to see that all the dead bone has been removed.

After removal of the dead bone the foul granulations by which it has been surrounded are scraped away, and the cavity resulting is douched with peroxide of hydrogen solution (ten volumes per cent.), after which undiluted carbolic acid is applied freely to its walls so as to purify it as thoroughly as possible. The skin is then brought together over the cavity by a few interrupted silkworm-gut stitches, but ample drainage should be provided for at both ends of the wound. The limb is put on a splint, and peroxide of hydrogen solution is used freely in the after-treatment. Under these conditions it may be possible to get gradual obliteration of the cavity if the disease has been only superficial and enough of the ensheathing layer has been removed. If, however, a persistent sinus should remain, one of the following methods for obliteration of bone cavity must be employed:—

OPERATIONS FOR THE OBLITERATION OF SEPTIC CAVITIES IN BONE

Closure of a cavity in bone is practically impossible as long as sepsis persists, and obviously the first step in the treatment is to secure asepsis; otherwise the cavity will discharge indefinitely. Sometimes it is fairly easy to make a cavity of this kind aseptic, but sometimes it is impossible. The easy cases are those where there is a single sinus leading directly into the cavity through an opening wide enough for the discharge to escape freely. When the cavity is small and the bone is large, as, for instance, when a sinus leads into a minute abscess in the head of the tibia, the possibility of removal of the septic area is increased.

In all cases every attempt must be made to eradicate sepsis before the operation for closure is undertaken. A free outlet for septic discharges must be secured, undermined areas of skin must be slit up, sinuses opened, drainage tubes of large size inserted, and an oxidizing agent such as peroxide of hydrogen employed. The cavity may be filled up from time to time in 1 in 20 carbolic solution, which is left *in situ* for ten or fifteen minutes so as to prolong its effect, and the cavity may be scraped with a sharp spoon from time to time under local analgesia, followed by the application of undiluted carbolic acid to its walls.

The operation for closure of the cavity may be undertaken when it is apparent either that the amount of sepsis is practically negligible or that the improvement under the above treatment has come to a standstill.

Its object is twofold; it aims first at making the cavity aseptic and then at securing its obliteration.

The parts must be purified with the most scrupulous care. All sinuses should be plugged with wool impregnated with liquefied carbolic acid, which must not be allowed to run over the sound skin. When this has been done, the skin around is purified in the usual manner, and then the orifice of each sinus is included in an elliptical incision and the entire sinus removed right down to the bone. Suitable incisions for exposure of the affected area are then carried down to the bone and the soft parts are turned back. These incisions will generally be parallel to the long axis of the cavity.

When the cavity has been properly exposed, the surgeon attempts to make it aseptic. The only really satisfactory method of doing this is entire removal of the walls of the cavity for a sufficient distance beyond the area of sepsis. With this end in view the cavity is first swabbed out with liquefied carbolic acid to destroy the more superficial organisms, and its extent is accurately defined with a probe; then all the walls of the cavity are removed with a mallet and chisel or gouge for a full quarter of an inch all round. The operation is practically similar to mortising a hole in wood, and the portion that is to be removed should be marked out on the surface of the bone in the same way before any is cut away. The chief difficulty lies in removing the floor of the cavity efficiently, but in cases of doubt there is no objection to going right through the bone and removing the compact tissue on the opposite side. The ordinary carpenter's mortising chisel is a useful tool for this purpose; in any case fine instruments should be used and great care must be taken to avoid fracturing the bone, as the amount removed will always be rather large compared with the thickness of the bone.

If the situation and size of the cavity allow of this procedure being carried out satisfactorily, it follows that it results in the production of an aseptic cavity; this is treated in the manner recommended on p. 691. Should it fail, however, the surgeon should try one of the following plastic operations before he considers the serious alternative of amputation or the vexatious one of abandoning active treatment in favour of lifelong drainage.

Plastic operations upon bone cavities. (1) *Bevelling off the edges of a cavity.* When a cavity in bone cannot be closed by the formation of tissue from within, the simplest alternative is to endeavour to effect its closure by causing the soft tissues outside to adhere to its walls and thus to produce a skin-lined depression in the bone. This may be done in some cases in a very simple manner. Thus when there is a long bone with a deep cavity running throughout the greater part of its length, and this cavity cannot be made to close in any other way, it may be converted into a broad flat groove or depression, into which the skin and subcutaneous tissues can be pressed so that they lie in close apposition with the bone, to which they will adhere in the course of healing. This method is specially suited for cavities in the tibia, and many successful results have been obtained in this way. The diagram

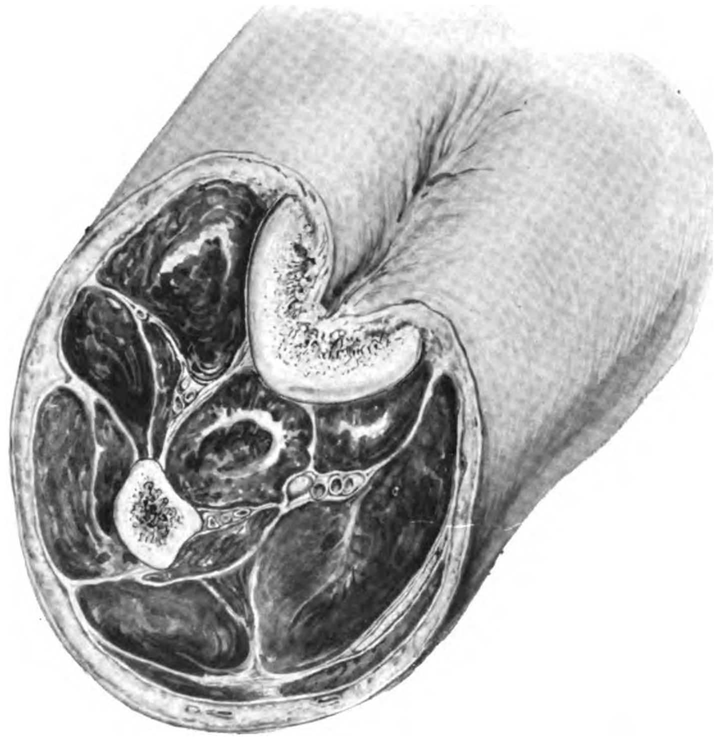


FIG. 272. OBLITERATION OF A CAVITY IN THE SHAFT OF THE TIBIA. The diagram shows how the soft parts are pressed down into the groove into which the cavity has been converted.

(see Fig. 272) explains how it is done. The method has the great advantage that complete asepsis is not essential for its success; should suppuration occur, the soft tissues will still adhere if satisfactory drainage be provided.

(2) *The use of skin flaps or skin grafts.* This method is similar in principle to the preceding one, and may be adopted for those cases in which the depth at which the bone is situated or the size or shape of the cavity prohibits satisfactory bevelling of its edges. It may be employed,

for instance, in the case of the femur, where the depth of the gutter in the bone from the surface is so great that the skin cannot be made to reach down to it. Under these circumstances Thiersch's skin grafts may be tried, or a skin flap fashioned from the thigh and retaining its connexion with it by means of a pedicle may be turned into the gap and pressed well down into contact with the bone. An abscess cavity in the head of the tibia may sometimes be treated in a similar manner. It cannot be said, however, that this method is very successful as a rule. Generally the amount of sepsis present or insufficient blood-supply of the flap brings about death of the graft.

(3) *'Stopping' the cavity with foreign substances.* A favourite plan with many surgeons is to make the cavity aseptic and then fill it with some foreign material, just as a tooth is stopped, and finally to bring the soft parts together over it and secure primary union. This is theoretically a simple plan, but the weak point in it is the difficulty of securing asepsis in these cavities and the certainty of failure if a foreign body be introduced into a septic cavity.

The first method suggested for stopping these cavities was the use of decalcified bone, or sponge rendered thoroughly aseptic. This was supposed to form a soft trabecular framework in which the blood-clot was caught and underwent organization. I have tried decalcified bone in many cases and have been almost invariably disappointed with the results. The slightest amount of sepsis causes it to deliquesce and escape from the wound, whilst in an aseptic case it is not necessary (see p. 653).

The more recent plan is the stopping introduced by Von Mosetig Moorhof of Vienna. This is a sterilized iodoform wax (iodoform, sixty parts; spermaceti, forty parts; and oil of sesame, forty parts). This is heated until it is fluid, and is poured, while still hot, into the cavity, which has been previously scrupulously dried.[1] It finds its way into all the crevices of the cavity and effectually stops it and then hardens *in situ.* The stopping should be made flush with the surface of the bone, and the soft parts are then brought together over it. Most surgeons advise that a drain should be left in, but this should not be necessary if asepsis has been secured.

This method has been strongly advocated, and much success has been reported by Von Moorhof and others. Personally I have had disappointing results, and, from a number of cases that have come under my notice, my conviction is that when it is possible to obtain a

[1] Professor Silbermark of Vienna takes the precaution of drying the bone cavity previous to the introduction of the wax by means of a hot-air blast from a special apparatus. This is to allow intimate penetration of the wax into the bone spaces, which restrains bleeding, and thus is antagonistic to sepsis.

really aseptic cavity it is easy to obliterate it by merely bringing the soft parts over it, but that every method of treatment is likely to fail when sepsis remains in the cavity. It is to the question of securing asepsis that the surgeon must devote his attention rather than to the particular method that he employs for obliterating the cavity.

REMOVAL OF A SEQUESTRUM DUE TO SYPHILITIC OR THE SO-CALLED 'QUIET' NECROSIS

These operations may be divided into those upon aseptic and those upon septic cases; the operations upon the latter have been described above. This distinction is of practical importance, for whereas it is comparatively easy to expose and remove a sequestrum in an aseptic case so as to secure primary union and permanent healing afterwards, the conditions are quite different in the case of septic necrosis.

Operations upon aseptic cases. Before operation is undertaken, the exact position, shape, and size of the sequestrum should be ascertained, if possible by means of a stereoscopic radiogram; this will help to determine to which aspect of the bone the sequestrum is nearest. The incision is planned according to the data thus obtained, and, if possible, exposure of the cavity containing the sequestrum should be effected by means of a flap that will cover the opening in the bone, so that the wound may be closed without drainage; the risk of leakage and subsequent septic infection is thereby greatly reduced.

The knife should go down to bone throughout when marking out the flap, so that the periosteum can be raised along with the flap when this is reflected. If for any reason it is impossible to do this satisfactorily, the flap should be raised first and the periosteum then incised crucially and turned aside with a rugine over the area of bone to be removed. The flap must be large enough to allow the sequestrum to be removed without risk of doing damage or of leaving portions of dead bone behind. The bone over the sequestrum is cut away with a gouge or chisel until the sequestrum is entirely exposed and can be lifted out of its bed with sequestrum forceps. The cavity left is carefully dried (for which purpose a few drops of adrenalin are excellent), so that it can be seen whether any spicules have been left behind and whether there is any granulation tissue that needs removal. An attempt is then made to secure primary union (*vide infra*), which often succeeds in these aseptic cases.

OPERATIONS FOR THE OBLITERATION OF ASEPTIC CAVITIES IN BONE

Indications. These operations are not confined to cases in which a sequestrum has been removed. After the removal of a myeloid sarcoma from a bone, for instance, a cavity is left which requires special measures for its closure.

The surgeon not infrequently excavates a deep trench in a long bone for the relief of pain in chronic osteitis and leaves a cavity comparable to that from which a sequestrum has been removed. This requires to be closed.

After a chronic abscess in the head of the tibia has been opened it is important that the cavity should be obliterated at once.

Operation. Many methods have been employed for this purpose; the majority of them are referred to in connexion with the closure of septic bone cavities (see p. 688). In my experience, however, they are rarely necessary in aseptic cases. The simplest method of obtaining closure here is to bring the soft parts together over the cavity, which is allowed to fill with blood-clot; healing of the soft parts occurs and is followed by gradual organization of the blood-clot. Many surgeons, in referring to this method, reject it on the ground that primary union is very difficult to attain under these circumstances, and that the wound almost invariably breaks down. This is altogether opposed to my experience. I have treated a number of bone cavities due to all the causes enumerated above with success by this method. Out of fourteen cases of which I have records, only one failed to heal by primary union; that was a myeloid sarcoma of the lower end of the femur in a young lady, which left a cavity in the condyles nearly the size of the closed fist after it had been enucleated. The hæmorrhage at the operation was profuse, and the oozing when the wound was sewn up was more free than was desirable. The result was a small subcutaneous hæmatoma, the contents of which were let out by separating the edges of the wound, and a sinus, discharging serum, remained for rather more than six weeks after the operation. This, however, then healed soundly and permanently without suppuration, and the patient has remained well up to the present time, a period of nearly four years. Careful examination of cases that have failed leads to the conclusion that the causes of failure are two in number, either sepsis, which is the more common cause, or too free oozing, which leads to the formation of a hæmatoma that has to be drained and is difficult to keep aseptic.

The preliminary steps of the operation have already been described (see p. 688). Absolute dryness of the wound should be effected before bringing the soft parts together over it. Exposure to the air often suffices to check the bleeding, but, should this fail, a few drops of adrenalin chloride (1 in 1,000) poured into the cavity may suffice. The cavity is watched to see the rate at which it fills with blood. If this occurs slowly, clotting will go on *pari passu*, and, by the time the cavity has filled, the soft parts may be sutured closely over it. If there is still oozing, the cavity may be washed out first with alcohol, then with alcohol and ether, and finally with ether alone. Following this, Silbermark's hot-air blast (see *Deutsch. Zeit. f. Chir.*, 1904, vol. lxvi, p. 589) may be employed, but it is rather difficult to use effectually. No drainage tube should be inserted; the pressure of the dressing serves to check venous oozing. The limb is put upon a splint, elevated somewhat, and, unless complications arise, is not dressed until the tenth day, when the stitches may be removed and the wound should be healed.

BONE-TRANSPLANTATION

During the past ten years bone-transplantation has been put upon a sound scientific basis. Much of this is due to the untiring efforts of Macewen of Glasgow, Murphy, and Axhausen. In order to have a thorough understanding of the subject, it is well to consider the theories of these various men and to see what bearing their work had upon our present-day knowledge of the subject.

Macewen advocated that the proliferation of bone in the transplant was due solely to the osteoblasts within the bone itself and that regeneration took place independently of the periosteum. He further advocated that the periosteum's sole function in the transplant was to limit the extent of bone regeneration.

Murphy was of the opinion that bone regeneration took place solely from the ends of the living bones and that the graft acted solely as a scaffolding for the reproduction of new bone.

Axhausen maintained that bone regeneration was from the periosteum and that the bone graft was absorbed and replaced by new bone.

These various theories have been more or less clarified and combined by the rather extensive experimental work of Phemister, who proved without a shadow of doubt that regeneration of bone takes place not only from the periosteum but from the endosteum and from the osteoblasts about the Haversian system. The life of the transplant is dependent upon its nutrition. Since the periosteum of the transplant is in direct contact with the fluids of the body and is readily permeable by capillaries, any osteogenetic cells which might be present will at once become active and of necessity bone regeneration will be much more prompt. The same applies to the endosteum. Owing to the fact that the osteogenetic cells which lie within the cortex of the bone are not in direct contact with nutrition, except that nutrition may reach them through the Haversian system, they of necessity will not proliferate so rapidly and regeneration due to these cells will be much slower than in the other two sources.

To summarize these various theories and to combine them into a sound scientific hypothesis, one might say that the bone in the transplant is absorbed and replaced by a process of 'creeping substitution.' As the bone of the cortex slowly disappears, it is replaced by bone derived from the osteogenetic cells of the periosteum, endosteum, and cells of the cortex which are in contact with nutrition.

It seems definitely well-established that Roux's law still holds true and that the transplant undergoes peculiar changes for functional adaptation depending upon its location and its requirements. Some observers, notably McWilliams, still believe that bone with the periosteum intact when transplanted into subcutaneous tissue and where there is no functional demand made upon it will live for an indefinite period of time and even have a tendency to proliferate. This is in marked contrast to the opinions of most scientific observers.

A bone transplant, if prepared according to our modern conception, should be taken from the same individual into which it is to be transplanted and should consist of the cortex with its covering periosteum and endosteum. Transplants taken from other individuals, if necessity demands such a procedure, should be taken from a near relative with the possibility of syphilis excluded.. Grafts taken from the lower animals usually do not survive, due to the changed serological reactions. They may, however, be used as scaffolding upon which surrounding periosteum or bone cells may grow.

INDICATIONS FOR BONE-TRANSPLANTATION

Murphy's classification of the indications for bone-transplantation cannot be improved upon. He tabulates them as follows:

1. To correct deformities resulting from defects of development, as aplastic extremital bones, congenital and acquired saddle-nose, aplastic mandible, spina bifida, etc.

2. To produce union in ununited fractures.

3. To replace bone removed by destructive infections, osteomyelitis, tuberculosis, lues, etc.

4. To restore or supplant fragments dislodged or destroyed by fractures.

5. To replace bone removed for non-malignant neoplasms, cysts, myelomas, osteitis fibrosa, etc.

6. To replace bone removed for incapsulated malignant disease, as giant-celled sarcoma, etc.

7. To immobilize joints, as, for example, those with too great looseness, resulting from Charcot joint or infantile paralysis, and for the cure of tuberculosis, as bone-grafting for a tuberculous spine.

TYPES OF BONE-TRANSPLANTATION

1. Transplantation of non-attached grafts.
2. Transplantation of attached bone grafts.
3. Transplantation of bone chips.
4. Transplantation of the shaft with its articular end.
5. Transplantation of periosteal flaps.
6. Transplantation of dead bone.
7. Transplantation of joints.

TRANSPLANTATION OF NON-ATTACHED GRAFTS

Technic. Bone transplants will not survive in the presence of any degree of infection. Consequently, asepsis plays a major rôle in the technic of bone-transplantation. No doubt a transplant will survive in the presence of an infection of low degree. In these cases there will be excessive production of bone with an irregularity in contour. This is partially due to the destruction of portions of the bone by infection and by the over-production of certain osteogenetic cells.

The proper time to do bone-transplantation depends upon variable factors. The observations of the military surgeons during the present war have proven to us that no aseptic procedure should be attempted upon bones under six months after the infection has apparently subsided. Carrel has shown that bacteria will continue to live encapsulated in living tissues and will remain viable for an extended period of time. There is only required a trauma and the production of a coagulum to allow these bacteria to again become active. It seems that after bacteria have been subjected to body tissue for a period of four to six months, they have been sufficiently devitalized or destroyed to allow us to undertake operative procedure with a fair chance of retaining a clean wound.

The part to be subjected to operative procedure should be shaven forty-eight hours before operation. This detail is observed for the reason that in the process of shaving the part very frequently small abrasions of the skin are produced by the razor. These become microscopically if not macroscopically infected and it is only reasonable to allow these infections to adjust themselves before the major procedure is instituted. The part should be mechanically cleansed, preferably with a very soft brush and green soap and washed with sterile water, followed by cleansing with 95% alcohol and ether. A sterile dressing is placed over the part. The same procedure of washing, only probably in a little less degree, can be instituted the following day. The sterile dressings are then left in position until the patient is placed upon the operating table, when they can be removed and the part painted with tincture of iodine.

The field of operation is surrounded by sterile linen. The scalpel which makes the primary skin incision is laid aside and the linen is fastened to the edge of the skin wound either with skin clips or Allis forceps. Another scalpel is used to carry the incision through the subcutaneous tissues and through the fascial planes. The muscles are separated either through the fascial planes or divided with a scalpel, thus the incision is carried down to the bone. The incision should be liberal enough to allow ready access to the area in which the transplant is to be made. The bleeding points are ligated in order to secure perfect hæmostasis. Caution should be here instituted in not placing too many catgut ligatures in the tissues. Crushing with forceps will at times suffice. No instruments or materials which enter this wound should be touched by the hand. The wound should be sponged with gauze compresses on forceps.

The ends of the bones are freed from the overlying soft tissues and the fibrous tissue at the ends is removed with bone-cutting forceps. The size of the transplant to be used is decided upon and the wound is then packed with sterile gauze. This transplant is taken from a suitable location—usually the anterior ridge of the tibia is chosen. The same technic is used for removing the transplant as was employed in the preparation of the bed. The transplant can be removed by circular saws driven by an electric motor, care being taken to retain the periosteal covering of the transplant. This transplant is not touched by the hand, but is held by forceps and placed in the bed prepared for it. It is preferable to fix the ends of the transplant into the adjacent ends of the living bone, either by allowing it to impinge in the medullary canal or to make a dove-tail and fasten it with bone pegs taken from the same individual. The transplant should never be fastened with non-absorbable material, such as nails, screws, wires, etc. These act as foreign irritating bodies and produce rapid absorption of the transplant and infection is much more likely to occur.

The soft tissues are closed by catgut sutures and the skin closed by either clips or silk sutures. The part should be immobilized and if there is a possibility of retraction due to the action of the muscles, an extension should be placed upon the part.

TRANSPLANTATION OF ATTACHED BONE GRAFTS

This procedure is rarely ever used at the present day, since it has no apparent advantage over the free bone transplant. Several operations have been devised. Chief among them are:

1. *Ollier's operation of pars renversement.* This operation consists of cutting a triangular wedge of bone with the periosteum attached from the end of one fragment, after the ends of the bone have been freed from fibrous tissue. This wedge is turned allowing the point to impinge on the fragment below, where it is fastened with chromicized catgut. In this case the periosteum is the permanent pedicle.

2. *Ollier's operation of pars glissement.* After the ends of the bone have been freed by removing the fibrous tissue, a triangular piece of bone is cut from the upper fragment with its periosteum intact. The soft parts are not separated from this fragment. The fragment is then pushed down in contact with the end of the bone below and fastened. In this case the soft parts form the permanent pedicle.

3. *Ollier's operation for implantation.* This operation is designed to replace a defect in one of two parallel bones. The ends of the fragments, as in the previous operation, are freed from fibrous tissue. A corresponding segment of the opposite bone is separated, allowing it to retain its soft tissue pedicle. This transplant is turned and implanted into the defect of the opposite bone, where it is sutured.

4. *Huntington or Hahn's operation.* This operation is designed for cases having an extensive loss of the tibia but with the fibula intact. Through an incision over the lower end of the upper fragment the end of the fragment and the fibula are exposed. The end of the tibia is freshened by removing the fibrous tissue. The fibula is cut off at this level, inserted, and fastened to the lower end of the upper fragment of the tibia. The wound is now closed. From four to six months later the upper end of the lower fragment of the tibia is exposed and freshened, as in the case of the upper fragment, the fibula cut off and transplanted into the upper portion of the lower fragment. The whole operation may be done at one sitting. In these cases the fibula soon takes on the size of the tibia on account of the demand placed upon it.

TRANSPLANTATION OF BONE CHIPS

In the certain cases where there is only a small amount of destruction of bone Macewen advocates filling this defect with bone chips. As demonstrated by Phemister, these chips are surrounded by nutrition, the osteogenetic cells from the cortex proliferate, and the chips become united by the process of callus formation, so that regeneration of bone is quite rapid. In these cases it is not necessary that the fragments have any attached periosteum for the reasons given above.

TRANSPLANTATION OF THE SHAFT WITH ITS ARTICULAR END

Roseving has transplanted a portion of the fibula with its articular end into the upper end of a resected humerus. Walther and De Gouvea transplanted the fibula into the lower end of a resected radius, each with apparently good results. The consensus of opinion is that the transplantation of the diaphysis of the bone with the epiphysis is not a reliable procedure. In cases in which the articular end of the bone must be removed better results are being obtained by doing an ordinary non-pedunculated transplant and later an arthroplasty according to Murphy's method or some modification.

TRANSPLANTATION OF PERIOSTEAL FLAPS

Codivilla after preparing the ends of the bone unites them with wire suture and then places about this suture a piece of periosteum to which is attached a small shell of bone. He removes this periosteum from a convenient bone. Brade uses the periosteum alone and obtains equally good results.

TRANSPLANTATION OF DEAD BONE

Crouch uses a graft of bone from which the periosteum and endosteum have been removed and the graft boiled and soaked in ether to remove the fat. This transplant is inserted in the same manner as an autogenous bone graft.

Küttner and Brewer have used a similar technic with apparently good results. In these cases the transplants are human bone taken after death and the transplant undoubtedly acts simply as a scaffolding, and with the absorption of the transplant regeneration from the ends of the living bone fills the corresponding defect.

TRANSPLANTATION OF JOINTS

This procedure has been almost a universal failure. Lexer reports a case of transplantation of an entire knee-joint, the graft being obtained from a cadaver eight hours after death. Due to an infection the entire transplant had to be subsequently removed and replaced by a graft taken from a freshly amputated leg. The latter gave fair results. The present-day status for the formation of joints seems to incline towards the reproduction of the diaphysis by a transplant and the subsequent formation of a joint by arthroplastic procedure.

CHAPTER III

OPERATIONS UPON FRACTURES

Operative interference in fractures may be required under a variety of circumstances. Thus the broken ends may have to be fixed immediately after the occurrence of the fracture, either in compound or simple fractures; on the other hand, operative interference may not be required until some considerable time has elapsed, when an operation will become necessary to rectify union of the bone in bad position or to remedy want of union. Thus we distinguish:

1. Operations upon recent fractures, including those upon (*a*) simple and (*b*) compound fractures; and

2. Operations upon fractures of long standing, including operations for (*a*) mal-union and (*b*) non-union.

OPERATIONS UPON RECENT FRACTURES

Indications. These include the operations which are performed before union has had time to take place. They will be:

(i) Operations undertaken as a matter of routine for certain fractures which cannot be treated satisfactorily otherwise; for example, those of the patella and the olecranon in which the line of fracture is transverse and the separation is marked. According to some surgeons, all oblique fractures of the tibia and the fibula also call for immediate operation; their view is that the obliquity of the fracture renders satisfactory apposition by splints impossible, and therefore the patient's ability to earn his living is seriously diminished. There is, however, no definite proof that such a statement is warranted; this subject is referred to more fully below.

(ii) Operations upon compound fractures in which the wound communicates freely with the fracture; and

(iii) Operations undertaken with the object of reducing a deformity which is irreducible by any other means, as in some cases of fracture in the vicinity of joints.

(iv) Operations undertaken for the fixation of fragments that it is impossible to keep in apposition by any other means. This important group will include many fractures involving an articular cavity.

Before proceeding to describe the various operations in use it will be advisable to say a few words with regard to the present state of opinion as to the advisability of operating upon fractures.

Operations upon recent simple fractures. Certain points are no longer in dispute. Thus all surgeons are agreed that *no fracture should be operated upon if it can be got into good position and maintained there by other means.* There is no doubt that operations upon fractures both recent and of long standing are still amongst the serious operations of surgery, and rank high among the cases in which asepsis is difficult to secure. The excessive extravasation of blood, the bruising of the parts, and the prolonged and often powerful manipulations necessary to secure and maintain apposition, all favour infection of the wound, and the operation, therefore, is not one to be undertaken by any one who is doubtful of his ability to secure perfect asepsis. It is essential, therefore, that operative interference should be limited to cases in which it is absolutely necessary. At the present time the success or failure of endeavours to set a fracture can be checked with accuracy by the X-rays, which should be employed in all cases of fracture both for diagnosis and for ascertaining the results of treatment. The appearances produced by the X-rays, however, may be extremely misleading if the ordinary single negative or a screen be used, and the best way to obtain really reliable knowledge of the actual condition of affairs is to make use of good stereoscopic plates, which define the relative positions of the fractured surfaces with great accuracy, so that the surgeon can base upon them not only his decision whether to operate, but the exact steps of the operation and even the position of the incision.

Another point upon which agreement is now general is that *all those fractures should be operated upon in which there is no possibility of getting the fragments into good apposition by any other means.* The chief examples of this class are those fractures of the patella and olecranon in which it is impossible to secure accurate adaptation by any other measures than operation.

After deducting these two large groups of cases there remains the still larger one about which there is some dispute at the present day. One school of surgeons holds that operation is called for in every case in which the apposition is not as good as could be reasonably expected after mechanical fixation of the fractured ends. Those who hold this view insist that an oblique fracture of the tibia and fibula should be operated upon at once, since it is practically impossible to get a fracture of this sort into really accurate apposition. Similarly, in fractures of the femur the fractured ends can seldom be got into accurate apposition and, although union occurs readily in the great majority of cases, a certain amount of shortening always results. Those who advocate routine operative interference hold that most, if not all, fractures of the femur should be treated by immediate operation for these reasons. On the other hand, there are surgeons of experience who never interfere in cases of simple fracture of this type unless they are called upon to do so either on account of faulty union or non-union.

The safest line of practice probably lies in the middle course between these extreme views, but the real difficulty is to determine which cases should be submitted to operation and which are best left alone. As already indicated, this difficulty is greatly diminished by the employment of stereoscopic radiograms. By means of them it becomes easy to ascertain the exact position of the fragments, and a fairly sound conclusion may therefore be arrived at as to whether union is likely to occur, and whether the patient is likely to have a useful limb when it does occur. Radiography has proved very valuable in this respect in recent years, and, thanks to it, certain general lines of treatment are beginning to be agreed upon.

Opinion is steadily inclining to the view that most *fractures implicating articular surfaces* should be operated upon without delay. These cases are difficult to deal with from the point of view both of coaptation and fixation. Fractures of the elbow-joint, for example, are exceedingly trying in this respect, but the subsequent usefulness of the joint is such an important matter that no effort should be spared to obtain success. The results obtained from early operation in articular fractures, although by no means perfect yet, are nevertheless superior to those obtained without it in the majority of cases.

Among the cases that present the greatest difficulty are *fractures of the shaft of the femur.* Here, after splint treatment, union can be rarely obtained with less than an inch shortening, which necessarily means a permanent deformity to the patient, and if this were the only point to be considered it would therefore appear that all fractures of the shaft of the femur, except perhaps those in elderly patients, would be better treated by immediate operation than by splints. But there are other considerations to be taken into account before this view can be accepted. Thus, for instance, it is well known that the operation is not free from danger; many cases of suppuration have occurred after an operation of this kind in the hands of most able surgeons, and even fatal results have been known. Even with the strictest aseptic precautions the operation has its own special risks, which can easily be understood when the mechanical difficulties of exposing, drilling, and uniting the fractured ends are remembered. Moreover, the question of sepsis is not the only difficulty. After the ends have been fixed in a perfectly satisfactory manner, the least laxity in the after-treatment may allow the fractured bone to bend at the seat of union, and deformity and shortening, as severe as that for which operation was practised, may ensue. This is most likely to occur when the operation is done some time after the accident and the muscles have become irritable and contracted, so that besides the initial difficulty of getting the ends into apposition, muscular spasm after the operation is very likely to reproduce the faulty condition.

My personal experience leads me to advocate operation within the first week after the fracture, provided that the patient be strong, and that a stereoscopic radiogram shows imperfect apposition and definite overlapping. At this period the fractured ends will be more easily cleared and drilled, and the muscles will not have become contracted; apposition, therefore, will be facilitated, and it will be much more easy to keep the limb straight afterwards. In feeble elderly people, on the other hand, operation should only be practised if there be such displacement as to render it unlikely that union will occur. In these cases ambulatory treatment in a Hoefftcke's splint answers excellently.

Multiple fractures generally require operative interference, as it may be exceedingly difficult to get more than one of the fractures into proper apposition without it. A radiogram, however, will be the best means of determining this point.

Fractures combined with dislocation invariably call for operation if the best result is to be obtained. Certain fractures, such as those of the clavicle, the shaft of the humerus, the ribs, and the metacarpal bones, rarely call for operative interference.

The question of mechanical fixation. There is a general impression that an operation upon a fracture necessarily means that mechanical fixation of the fragments should be practised. Although such a procedure may be necessary in the majority of cases, it is not by any means invariably so. It is obviously better to avoid the presence of foreign bodies in the wound unless they are absolutely essential, and therefore all forms of fixation apparatus should be abandoned when the conditions allow of it. The chief factors that will influence the decision on this point will be the size and direction of the fractured surfaces. Broad transverse fractured surfaces do not tend to become displaced after correct coaptation has been secured; perfect apposition may also be secured without risk of displacement when the fragments are rough and serrated, and the serrations can be made to fit into each other accurately so as to restore the bone to its normal contour. Under these circumstances the muscular tone will keep the fragments in apposition, and only ordinary care in putting up the limb on a splint is required to prevent recurrence of the deformity. When, however, the fractured surfaces are very oblique some form of mechanical fixation is generally necessary. The remarks apply more particularly to cases of compound fracture.

The more care and skill a surgeon spends on the coaptation of the fractured ends and the application of splints under full anæsthesia, the less frequently will operative interference be called for.

The time at which to operate. Extended experience convinces me that when a fracture requires operation the sooner this is practised the easier it is to do, and the better the final results are. Early operation implies that the fractured ends are much as they were when the fracture occurred, and it is therefore easy to turn out the clot from around the seat of fracture; since the bone ends are in their normal rough condition they can be fitted accurately together, and due advantage can be taken of any interlocking projections that may be present. This ensures absolute accuracy in adapting the fragments. Delay in operation, on the other hand, means that the soft parts become œdematous and infiltrated with adherent blood-clot, the muscles become tonically contracted so that it is difficult to stretch them sufficiently to obtain proper coaptation of the broken ends, and considerable violence may have to be employed, a point of great importance when the difficulty of keeping some of these cases aseptic is remembered. When callus is forming, the fractured ends get rounded off and are less easily adapted to each other. The infiltrated muscles are also in a state of irritation, and may give rise to trouble after the operation from their tendency to contract. For the last five years I have been in the habit of operating much earlier than was formerly the case, and the greater facility with which the operations can be carried out under these circumstances has impressed me strongly with the desirability of operating within a week of the fracture, and if possible, within the first three days. This period is quite long enough to determine whether non-operative measures are likely to succeed; indeed, with a good X-ray installation it should be possible to arrive at a definite conclusion as soon as the result of a determined attempt to set the fracture under anæsthesia has been ascertained, so that there should be no excuse for delaying operation unnecessarily.

Operation. An essential point in all these cases is to secure thorough disinfection of the field of operation and its vicinity. The entire limb should be shaved and purified with the greatest care. It is difficult to foresee what parts of the limb will have to be manipulated by the surgeon or his assistants, and from what I have actually seen I am convinced that a potent cause of the frequent occurrence of sepsis in these cases is contact with unpurified skin during the manipulations necessary for coaptation of the fracture. It is impossible to tell beforehand what difficulties may be met with in any given case, and a careful observer will often notice that the hands of the surgeon or his assistants come into contact with parts that have not been purified previously, owing to the impression that the case would be easier than it turns out to be in practice. Therefore it should always be the rule that the whole limb should be purified, and that part of it not concerned in the operation should be wrapped up in sterilized cloths firmly fastened on by pins or sterilized bandages. Tincture of iodine is most useful as a skin disinfectant as it renders visible what area has been disinfected and what has not. It renders manipulation of the limb during the operation both easier and safer if a sterilized linen stocking or sleeve, as the case may be, is drawn on over the limb after the tincture of iodine has been finally applied. This may be tied round the limb or clamped to the skin with forceps.

The incisions should be free, and so planned as to allow of access to the seat of fracture with the least injury to the soft parts. In the case of the thigh the incision will be usually on the outer side, whilst the ulna is best reached along its subcutaneous border, and the radius along its posterior aspect. The actual incisions will often be determined by an inspection of stereoscopic radiograms. Free incisions are required, because it may be necessary to employ some fixation apparatus to the bone, which cannot be done with ease except through an incision that exposes the bone ends freely, and allows them to be manipulated without undue bruising of the soft parts. Moreover, the surgeon will find it much easier to deal with the fracture if he has the soft parts incised sufficiently; few things are more difficult than to get the fractured ends into satisfactory apposition through an insufficient incision.

All blood-clot is turned out, and any soft structures intervening between the fractured ends are got out of the way. The fractured surfaces are as fully exposed as possible and their relative displacement is noted. Any loose fragments are carefully removed with forceps and preserved in a sterile cloth. Traction is then made upon the limb by an assistant so as to bring the fractured surfaces to the same level, and, when this has been done, the surgeon manipulates the limb so as to get them into accurate apposition. It should always be possible to obtain this in recent cases, except when there is great comminution. The fractured ends are rough, and the surfaces can be made to fit accurately as soon as the muscular contraction has been overcome. In very muscular subjects spinal anæsthesia is valuable in overcoming muscular spasm. After coaptation has been obtained, the extension is relaxed, and the tension of the muscles should keep the fractured ends in apposition if they have been made to fit, and the line of fracture be not too oblique. If the ends of the bone betray a tendency to slip out of place they can be fixed with Peters's or some similar forceps (see Fig. 273) or a suitable clamp (see Fig. 274) while preparations are made to fasten them together.

When there is no tendency to displacement after the fractured surfaces have been got into apposition, the limb is held immovable by the assistant whilst the soft parts are brought together over the fracture and the wound is closed without a drainage tube. A light sterilized metal splint is then moulded to the limb and incorporated in the dressings. Outside this a firmer splint of wood may be applied if necessary. This method applies especially to compound fractures in the upper extremity.

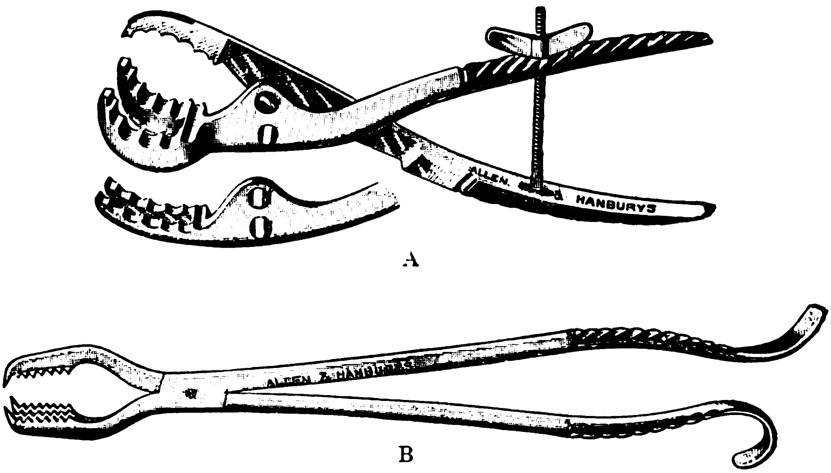


FIG. 273. BONE-FORCEPS. A shows the form known as Peters's, which are very useful as they do not require an assistant to hold the blades together. The forceps are fixed in position by the screw on the handle, and the drill is inserted between the limbs of the upper blade. The blades are interchangeable and are made for use on different bones. B shows Lane's pattern with very long handles and therefore a powerful grip.

Methods of mechanical fixation. When it is necessary to fasten the fragments together one of the following methods must be employed:

(1) *Absorbable sutures.* A certain number of surgeons make use of sutures of absorbable material, such as catgut or kangaroo tendon, in order to avoid leaving permanently in connexion with the fracture a foreign body that may give rise to trouble at some later period. Trouble from this cause has been known to happen in many cases, and the objection to unabsorbable materials, therefore, is a perfectly valid one. The drawback to the use of absorbable sutures is partly that they are not strong enough to bear the strains to which they may be exposed in certain cases, and partly also that an elastic material such as catgut or kangaroo

tendon is not rigid enough to keep the ends of the larger bones in proper contact. For fractures such as those of the patella and olecranon, for which they are most frequently used, they are hardly to be recommended, as they cannot be relied upon to stand enough strain. American surgeons, however, depend almost entirely upon catgut suturing in such cases and claim satisfactory results. For the few cases in which the object is rather to prevent lateral displacement than shortening of the limb they may be advantageously employed; for example, for fractures of the fibula where the tibia is not broken.

(2) *Unabsorbable sutures.* The principal unabsorbable sutures are silk and wire; of these, *silk,* although strong enough to bear any reason-

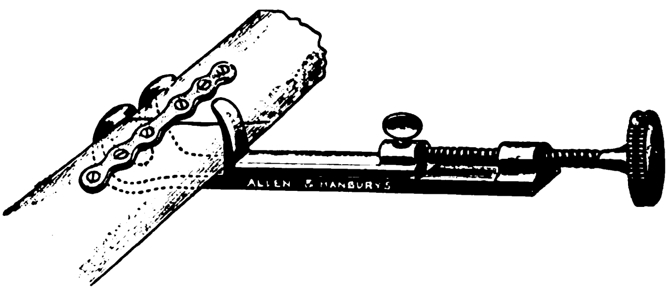


FIG. 274. CLAMP FOR MAINTAINING COAPTATION OF A FRACTURE. This apparatus can be used either to maintain the fractured ends in position pending their mechanical fixation or as a fixation apparatus itself. In the latter case it is surrounded by the dressings and removed during the third week when all risk of displacement is over. It is best adapted for compound fractures.

able strain to which it may be exposed, is too pliable to secure perfect apposition. It may, however, be used for cases of transverse fracture of such bones as the patella, or particularly the olecranon, when the subject is not unduly muscular. In a muscular subject a silk suture strong enough to bear all the strain to which it would be liable would have to be so stout as to approximate to the gauge of wire. The only advantage it offers over wire is that the knot is not so prominent, and is therefore less likely to cause irritation and require removal.

Silkworm-gut is hardly to be recommended in any case. Its strength is not much greater than stout silk, its pliability is very similar, and the irritation caused by the ends of the knot is greater than those of silk, closely approaching that of wire.

Wire is one of the most generally useful of all fixation methods for bone. It is usual in England to employ pure silver wire of various gauges, No. 4 to No. 7,[1] according to the various bones that have to be wired.

[1] This is the French catheter gauge.

Thus, for the femur No. 7, for the tibia No. 6, for the patella No. 5, and for the olecranon, radius, ulna, and fibula, No. 4 is sufficient. In America, aluminium-bronze wire is advocated by many surgeons, and is very pliable. It is also frequently used in fractures of the long bones, particularly in oblique or irregular fractures, where the wires can be introduced as shown in Fig. 275, A; in these cases, however, its use involves more disturbance of the bone ends than does the application of a

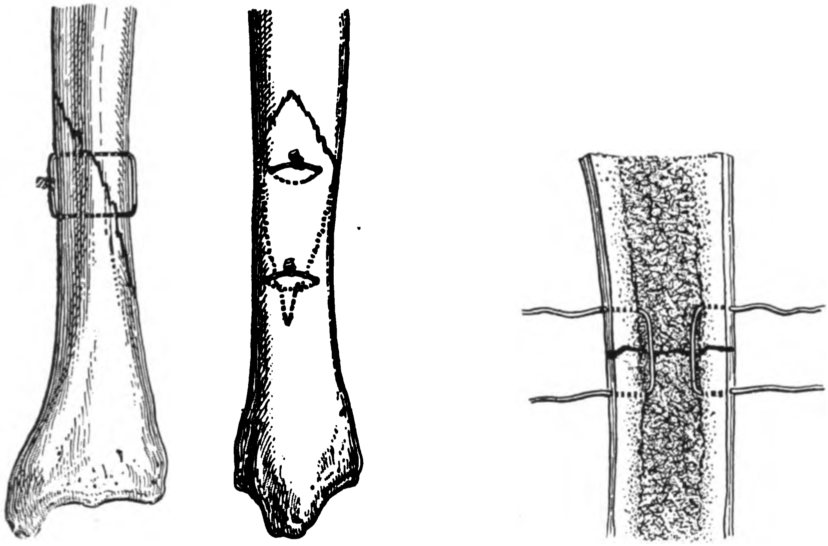


FIG. 275. WIRE SUTURES FOR OBLIQUE AND TRANSVERSE FRACTURES. A shows the simplest method of inserting the wires. There are many other ways which it is unnecessary to illustrate. With a stout wire twisted firmly practically no displacement is likely to occur provided that the limb is properly immobilized subsequently. B shows a method that is only suited for transverse fractures with pronounced serrations. It is obvious that these sutures can only restrict but not abolish lateral displacement.

bone plate. In cases of transverse fracture, however, the wire has to be introduced as depicted in Fig. 275, B, and under these circumstances there may be slight transverse displacement in spite of the wire, and, besides that, lateral bending may occur if there be much lateral strain. This is sometimes a matter of great importance in single bones like the femur and the humerus, and for them other methods may be required; but for the clavicle, the patella, and the olecranon, wire is, on the whole, the best and most easily managed method of fixation.

(3) *Screws, nails, and pegs of metal or ivory.* Reasoning from the analogy of carpentry, the easiest and best method of fastening two bone

surfaces together is clearly by nails, pegs, or screws. Sir Arbuthnot Lane at one time advocated long plated screws with a cylindrical shank instead of the tapering one found in the ordinary screw, but these have been generally given up in favour of the 'bone plates' described on p. 711.

Nails and tacks may be used either alone or in association with some form of plate or collar which they fasten to the bone. Long nails are sometimes more useful for fractures in which they can be introduced at right angles to the pull of the muscles; they are less likely to split the bone than pegs or screws. They have been used with success in fractures into the knee and elbow joints, and particularly in fractures of the neck of the femur in which they are driven into the outer surface of the great trochanter, and made to traverse the whole length of the neck whilst the fractured ends are held in position. *Short nails or tacks* are also quite useful in reattaching portions split off from a bone that cannot be fastened in place with a bone plate; for example, portions of the tuberosities of the humerus, the malleoli, or the great trochanter.

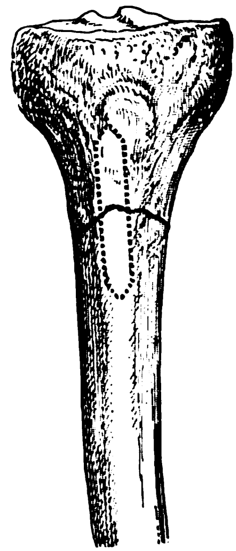
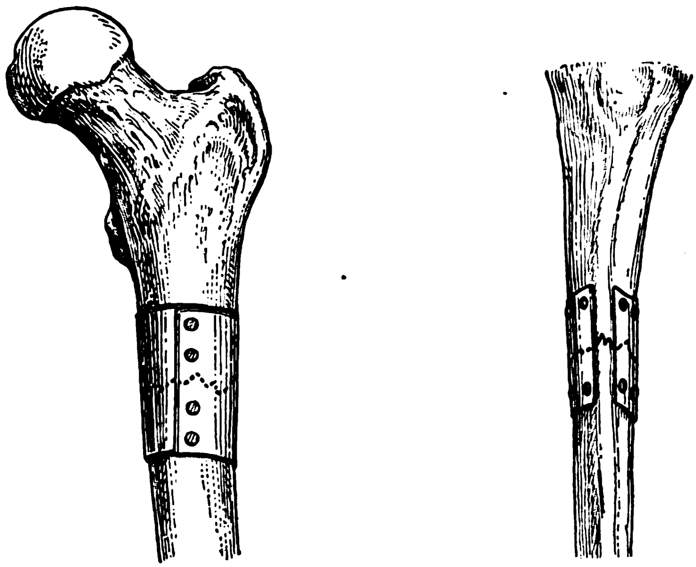


FIG. 276. BONE PEG FOR THE FIXATION OF FRACTURES. The peg is inserted into the centre of the bone. The chief difficulty is to get it into position, as the ends have to be widely separated. It is less suitable for the position in which it is shown in the figure than those mentioned in the text.

Ivory pegs are also advocated by some and have a definite sphere of usefulness. More than once I have successfully used the old plan of inserting an ivory peg between the two fragments in the long axis of the bone as shown in Fig. 276, after other methods had failed. The few cases in which this plan will be more useful than any other are those in which the fracture is near an articular surface, particularly the ankle- or wrist-joint, and the lower fragment is either so small that a metal plate or collar cannot be satisfactorily applied, or is so surrounded by tendons and tendon sheaths that the application of a plate or a collar might be detrimental to the subsequent movements of the joint. The place of this method, however, has been almost entirely taken of recent years by the application of the bone plate.

Metal pins, such as steel knitting-needles, are sometimes employed in fractures into the knee- or elbow-joint, particularly the latter, and in some cases of fracture of the neck of the femur. The best way to employ them is to have the parts held firmly in accurate apposition and then to drill the fragments from side to side and to pass one or more



A B

Fig. 277. Metal Collars and Plates for the Fixation of Fractures. The metal is often perforated with holes beforehand. The best plan, however, is to wrap the collar round the bone so that its ends overlap, and then punch holes through the overlapping ends into the bone. This clinches the collar and gives a firmer hold. This method is shown in A, but as it is difficult to apply to triangular bones like the tibia, two plates may be substituted for it in these cases as shown in B.

Fig. 278. Lane's Bone-plate for Fractures. The drawing is half the natural size and will give an idea of the size and rigidity of the plate. It is made either of highly tempered steel or of steel sufficiently mild to be bent with suitable wrenches. The plate shown above would be suitable for a fracture of the femur.

long steel pins or knitting-needles through the drill holes, leaving the ends projecting from the wound; the pins are removed ten days later. This method is most suited for those cases in which other means of mechanical fixation would cause a projection on the articular surface that would interfere with free movement; it is therefore occasionally called for in comminuted fractures involving the elbow-joint. The chief difficulty, however, is boring the hole for the pins. The only really

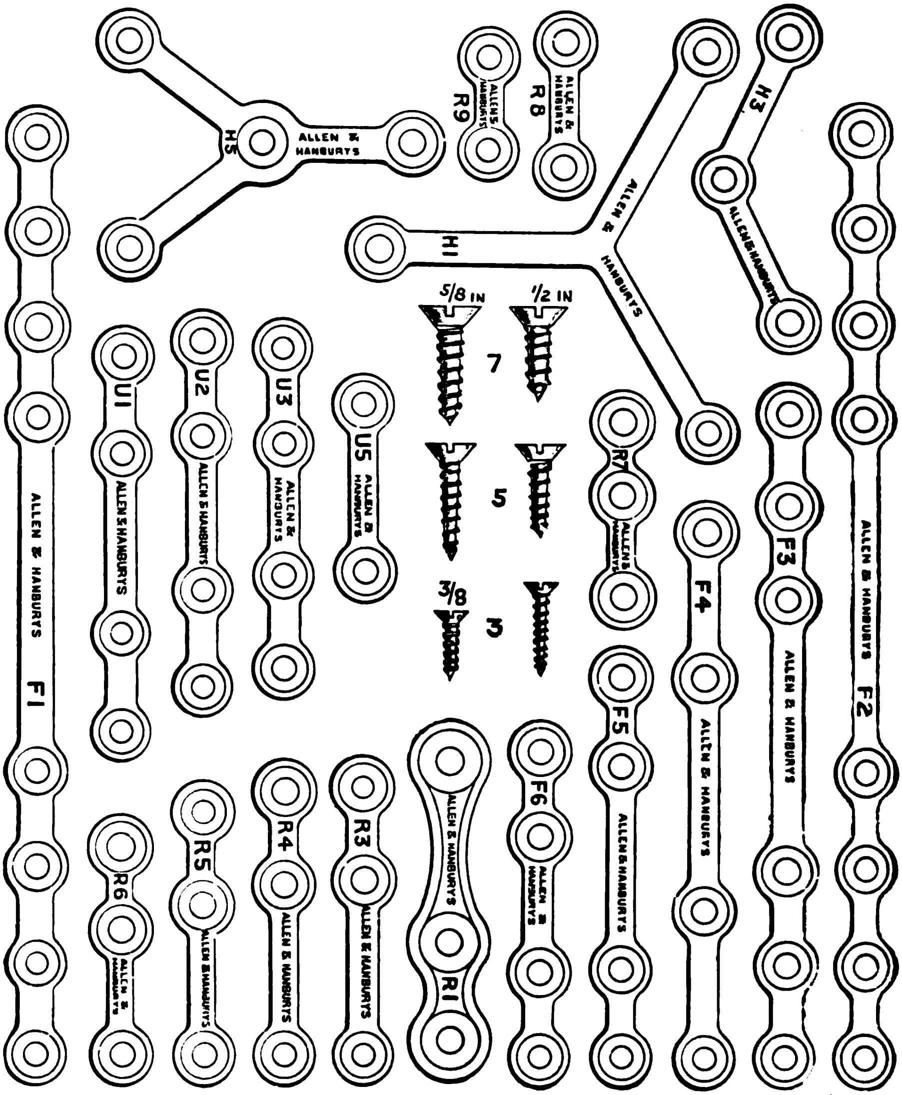


FIG. 279. LANE'S SCREWS AND PLATES FOR FRACTURES. The plates are fastened on with the small screws, which are of different sizes and lengths to correspond with the different plates with which they are used. It will be noted that the thread of the screw extends right up to the head. The chief sizes of the different plates are shown; each is marked according to the size of the plate and the bone for which it is suitable (F = femur, H = humerus, R = radius, U = ulna). The Y-shaped plates are suitable for fractures of the lower end of the humerus.

satisfactory way of doing this is by means of a long drill driven by an electric motor; this penetrates the bone rapidly and without requiring any force, and thus there is little risk of displacement of the fragments. It is difficult to avoid causing displacement from pressure of the drill if the boring be done with the ordinary hand-drill.

(4) *Metal plates and collars.* Metal supports at the seat of fracture, which generally take the form of plates or bars, have been used for some time and have recently become very popular. Obviously the most workmanlike method is to surround the bone with a metal collar perforated with holes in the necessary places, and fastened on by tacks or screws of the same metal as the plate so as to avoid setting up any electrolytic action (see Fig. 277). Parham has introduced a band that may be applied much more simply, and Cotton has devised an ingenious application for circular wire support. The use of a collar of this kind, however, has certain drawbacks which has led to the plate being preferred to it. Thus, its application involves much more disturbance of the fractured ends than does that of a plate which is simply applied to one surface. Further, while the application of a collar is comparatively easy in single round bones like the humerus and the femur it is out of the question in a triangular bone like the tibia. Finally, it is clear that in those cases in which they could be most easily used—viz. fractures of the femur or humerus—they must yield to the bone plates not only in ease of application but in strength—a very important point in fractures of these particular bones. The supports that are in general use at the present time are the bone plates of the form shown in Fig. 278. These are fastened to the surface of the bone with small screws which just penetrate through the compact tissue. One, two, or more plates are applied according to the length and direction of the fracture. The plates are of various thicknesses to correspond to the strength of the various bones and can be bent or twisted by suitable wrenches to lie flat on the surface of the bone. Generally it is advisable to insert two screws on each side of the line of fracture in order to prevent angular deformity, but if the plate be furnished with points like staples (see Fig. 280) one screw on each side will suffice in the case of the smaller bones.

The advantage of this method is that it is the simplest method of maintaining perfect apposition. When the bone ends have been fitted together the plates are just applied to the surface without the need for further exposure or displacement of the fractured surfaces. This is a great advantage in cases of recent fracture in which perfect anatomical restoration can be obtained and maintained quite easily. The method also finds a most useful application in cases of ununited fractures in which the muscles have become permanently shortened; the first difficulty here is to get the ends in apposition, and it is most important to keep them there when once this has been done. The bone plates serve the latter purpose admirably. They can be so arranged as to take the strains to the best mechanical advantage.

(5) *Bone clamps and similar special instruments.* Parkhill's ingenious instrument, or some modification, may be of value in certain cases, although most surgeons will agree that it is rarely necessary in simple fractures, and it is admittedly difficult to apply properly. The clamp must be left projecting from the wound and included in the dressing, and the risk of sepsis, therefore, is not to be denied. Nevertheless, it, or some modification of it, is largely used by some surgeons both in Europe and America with great success in simple fractures. It might certainly be used advantageously for compound fractures of the femur or the tibia in which there is difficulty in maintaining apposition by other methods. It gives a very firm hold, and is therefore valuable in muscular subjects, especially those who are liable to be attacked by delirium tremens. It keeps the bone ends in apposition until the exudation around has had

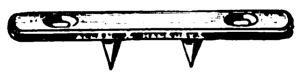


FIG. 280. BONE STAPLE-PLATE FOR FRACTURES. These plates give an excellent hold. They are screwed on to the bone.

time to fix them, and after its removal no foreign body is left in the wound. The risk of necrosis is therefore diminished.

BONE-TRANSPLANTATION IN FRACTURES

Due to numerous failures in employing foreign materials in the treatment of certain types of fractures and non-union of bones, and in view of the fact that bone-transplantation has offered so much in the correction of bone deformities, bone grafts have been almost entirely substituted in certain types of fractures where mechanical appliances other than splints have been required. Bone grafts probably give the best results in certain conditions, namely, non-union and mal-union of fractures, fractures with destruction of a considerable portion of bone and with mal-position of the fragments.

TYPES OF OPERATION

1. *Intramedullary splints.* In certain fractures of the long bones, notably femur, tibia, fibula or humerus, whether there be non-union or mal-union, destruction of bone or mal-position of bones, this type of

operation has been extensively employed. Strict aseptic technic, as in bone-transplantation, is absolutely necessary. The ends of the bone are well exposed, and in case of mal-union the callus is excised and the medullary canal well opened. A graft is taken from the sound tibia according to the technic of bone-transplantation (*v.s.*), and is cut to a suitable size to fit the medullary canal. Murphy advocated the reaming out of the medullary canal in order to remove the endosteum and to form a bed for the implant. The fractured limb is bent and the graft is driven

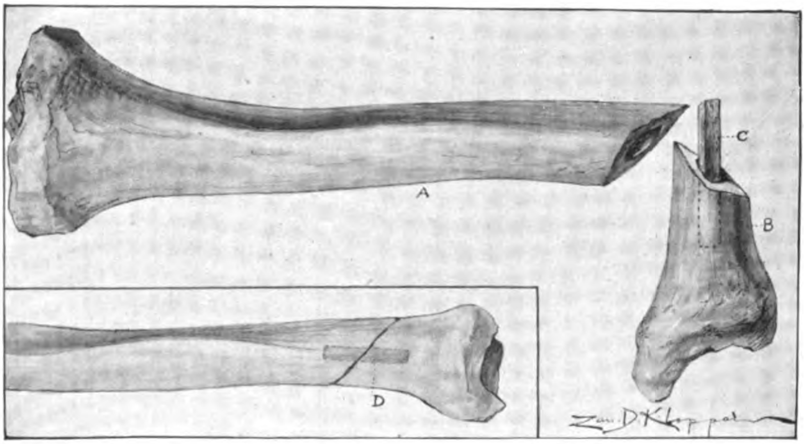


FIG. 281. DIAGRAM OF METHOD OF INSERTION OF INTRA-MEDULLARY BONE SPLINT. Note that the splint is inserted into one end and the bone fragments then bent at an angle, so that the splint can be slipped into the opposite fractured end.

into the medullary canal of one fragment. The other fragment by angulation and traction is then placed over the graft and the latter allowed to slip into the medullary canal (see Fig. 281). The wound is closed without drainage and a light splint applied. Care should be taken that the graft is not displaced upward too far to allow sufficient introduction into the medullary canal below to maintain proper apposition. This can often be overcome by holding one end of the splint in the medullary canal by a peg while the other end is slipped into the medullary canal.

2. *Sliding graft—Albee operation.* As in the previous operation, the ends of the bone are freed and are placed in apposition. They can be held by a suitable clamp, such as the Schroeder clamp. With a circular twin saw adjusted to about 11 mm. apart in the femur a wedge is sawed, making the transplant of the longer fragment about twice that of the

shorter fragment. The cut in the bone is carried to the medulla in the shape of a trough, whose periosteal side will be about 6 mm. wider than the medullary side. The ends of the graft are freed by a sharp thin chisel. The wedge from the short fragment is removed and the longer slipped down. The wedge removed can be placed in the trough above, or possibly it can be utilized for pegs. This splint is held in position by pegs, preferably taken from the portion of bone removed, and placed obliquely into the cortical bone on either side of the gutter, with their

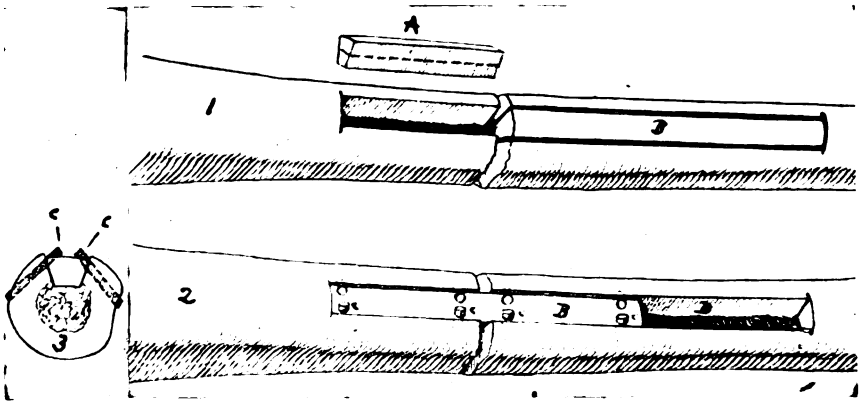


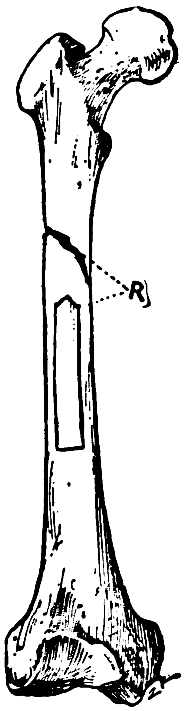
FIG. 282. DIAGRAM ILLUSTRATING APPLICATION OF INLAY GRAFT TO FRESH FRACTURES. Preferable to Lane plate. On account of the absence of any marked pathological change in the fragmented ends of fresh fractures, bone material from this source can be used to advantage, as can be seen from the cut. In 1, *A* and *B* are removed with the motor saw. *A* is split into narrow strips of bone, which are made into proper sized pegs with the Albee dowelling instrument. *B* is then placed into position as indicated in 2 and 3 and firmly held in place by dowels (*c-c-c*). The space in the cortex (*D*) remains empty.

ends projecting over and in contact with the periosteal surface of the graft (see Fig. 282).

The advantage of this operation is that all the work is carried on in one wound. There is no foreign particle introduced and the medullary canal is not close and there is proper fixation and immobilization of the fragments.

3. *Sliding intramedullary splint—Hoglund operation.* This operation is very similar to the Albee operation. With parallel twin saws a vertical graft from 7 to 10 cm. long is cut in the cortex of the longer fragment at a distance of about 5 cm. from the line of fracture. The distal end of the fragment is cut by a sharp chisel and the proximal end, that is the end near the fracture line, is removed in a similar way with a

point (see Fig. 283). This graft after the bones have been placed into apposition is displaced into the medullary canal and forced up through the fracture line to impinge into the medullary canal of the fragment above (see Fig. 284). This graft can be held in place by pegs or by



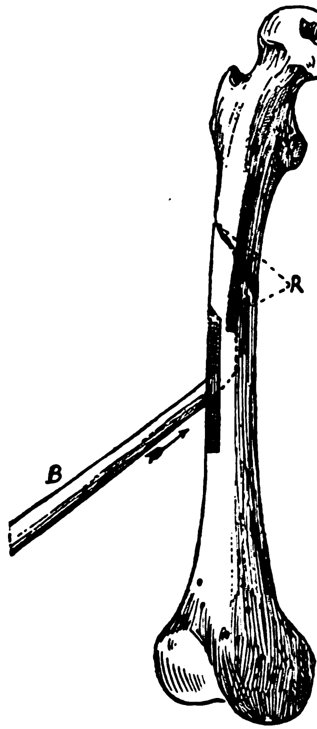


FIG. 283. (*At left*) *R;* THE DOTTED LINES IN PICTURE INDICATE THE BONE RING WHICH HOLDS THE SPLINT IN PLACE.

FIG. 284. SHOWS THE SPLINT DRIVEN INTO THE BONE RING, EXTENDING HALF AND HALF IN EACH FRAGMENT. (Part of same plate described in Fig. 283. Represents drawing at right of plate.)

appropriate screws made at the time of operation from fragments of bone.

4. *Fixation by bone pegs.* In certain fractures, notably fractures of the neck of the femur with marked displacement, it is often possible to hold the fragments in position with pegs driven into an appropriate canal previously prepared. In a fracture of the neck of the femur with displacement traction is made upon the leg, either by placing the patient upon a Hawley table or by ordinary direct traction, until the shortening is overcome. With a narrow chisel a canal is cut from just below the

external surface of the great trochanter through the cortex and cancellous portion of the upper end of the femur through the neck. By measurement a suitable graft is taken from the anterior ledge of the tibia and

FIG. 285. ROENTGENOGRAM OF NECK OF FEMUR SHOWING BONE TRANSPLANT IN POSITION. (Taken four months after operation and showing bony union of fracture.)

cut to appropriate size. This peg is then driven into the canal prepared, care being taken to avoid puncturing the articular surface of the head of the femur (see Fig. 285). The part can be placed in a light cast for immobilization for a short period of time.

A similar operation can be utilized in the neck of the humerus.

STEINMANN NAIL-EXTENSION

In certain fractures with over-riding in which it is impossible to secure apposition of the bones or in which sufficient extension cannot be obtained by applying adhesive strips Steinmann has advocated applying direct traction to the bone. This operation is especially applicable to fractures of the tibia in which traction is made from the os calcis or the lower end of the tibia, fractures of the lower end of the femur where traction is made from the condyles, and fractures of the humerus where traction is made from the lower end of the humerus.

A small puncture incision is made on the lateral surface of the part of the bone to be employed. This incision is carried down to the bone. Then a hole is drilled completely through the bone. A special iron pin is inserted through the bony canal and brought out through a puncture wound on the opposite side. The wounds are closed and sealed and traction made from this pin.

Possible objections to this operation are that the pin acts as a foreign body and plus the pressure brought about by traction produces a rather rapid absorption and liquefaction of the bone, which offers a favourable location for bacterial growth. Complications following the procedure, however, are rare.

Operations upon recent compound fractures. Although it is not absolutely essential that all cases of compound fracture should be operated upon, yet a large majority of the cases will require some form of operative interference, and there is not nearly so much divergence of opinion as to which cases should be submitted to operation and which should be treated without it, as there is in the case of simple fractures. Broadly speaking, it may be said that all cases should be operated upon in which the wound communicates freely with the fracture, and in the majority of these it will be advisable not only to trim and purify the soft parts and the fractured surfaces, but also to get the broken ends into position.

Operation. In the first place, the wound and a considerable area of skin must be purified with great care. The success of the operation depends upon this, and no effort should be spared to secure complete asepsis. Many surgeons at the present day swab out the wound freely with a 2% alcoholic solution of iodine, and then trust to drainage. Of this plan I have no personal knowledge. Much as I like tincture of iodine for skin purification, I am still in the habit of using a very powerful disinfecting agent in these cases. On the whole, I have found the best plan is to plug the wound tightly with gauze wet with a 1 in 1,000 solution of perchloride of mercury until the surface of the gauze lies flush with the skin, which is then purified in the ordinary manner for a wide distance around the wound, the parts beyond the purified area being wrapped up in sterilized towels. The gauze packing is then removed from the wound, which is opened up in any direction that may be necessary to give free exposure of the deeper parts. All blood-clot is turned out, and any badly damaged tissue snipped away with scissors. The whole raw surface is then mopped over with undiluted carbolic acid, care being taken to see that no recesses of the wound are overlooked. Finally, the bone ends are exposed, and if they be dirty or have protruded from the wound they are not only scrubbed with a nail-brush and a 1 in 20 carbolic lotion, but the superficial layers of the fractured ends are gouged or chiselled away, and undiluted carbolic acid is applied to the surface left; it is unnecessary, however, to do this unless the fractured ends have been obviously infected. Efficient drainage must be provided, either through the original wound or through suitably placed counter-openings.

This method of treating the wound may appear somewhat heroic and in some cases is possibly unnecessary, but it must be remembered that, in the first place, primary union is never aimed at in these cases; owing to the risk of infection it is unwise to suture the wound without securing ample drainage, and therefore the irritation produced by the acid on the tissues is of little moment, whereas it is an effective germicide provided that it has free access to the soiled tissues. In the second place, all the factors most conducive to sepsis are present in these cases, and slight septic infection may end disastrously. The muscles are badly bruised and are in a state of irritation, they retract and leave large irregular spaces in which blood collects and coagulates, and the interior of the bone communicates with the wound; any infection of this area spreads rapidly, and is very serious. I have used this method in many severe cases and have been astonished at the good results that have followed its use. Milder methods may succeed in simpler cases, but the plan recommended above will generally save any case of compound fracture that does not call for immediate amputation.

After drainage has been provided for, the question arises whether or not fixation apparatus should be used to secure the fractured ends. The use of any unabsorbable fixation apparatus in compound fractures is likely to be followed by necrosis requiring the removal of sequestra and the fixation apparatus should the primary attempt at securing asepsis fail, and therefore many surgeons dispense with them whenever this is possible; when it is absolutely necessary to resort to them they use either absorbable sutures, such as catgut or kangaroo tendon, or some easily removable form of apparatus, such as metal pins that project from the wound, Parkhill's bone clamps, or one or more silver wires surrounding the bone, with their ends projecting from the wound. The clamp shown in Fig. 274 is useful for this purpose.

The object of the removable forms of fixation apparatus is to keep the bone ends in apposition until sufficient consolidation has occurred to warrant their removal; this is then effected with the least possible disturbance to the structures about the seat of fracture. Provided that no necrosis has occurred, the period of convalescence is not thereby materially prolonged. Therefore it is well to avoid all such apparatus as would be likely to give rise to necrosis were slight sepsis to occur in the wound.

After-treatment. A good splint for these compound fractures is a plaster-of-Paris casing. In order to get proper access to the wound for the subsequent dressings, the splint should be arranged with a wide interruption opposite the seat of fracture. The interruption can be formed by two or three strips of malleable iron, the ends of which are incorporated in the two portions of the casing, and the centre parts bent out sufficiently to allow the dressings to be applied beneath it; the interruption should be wide enough to prevent all risk of discharge soaking away underneath the casing. In cases of compound fracture of the femur the plaster-of-Paris casing may be made to take in part of a Thomas's hip-splint.

OPERATIONS UPON FRACTURES OF LONG STANDING

Operations for ununited fracture. Indications. All ununited fractures require operative interference. The chief difficulty, however, is to know when any given case falls into this category. By the term 'ununited fracture' is meant a fracture in which consolidation will not occur spontaneously, but the difficulty is to know exactly when incomplete or defective union becomes true non-union. In times past operation was never undertaken until after the lapse of some months, and until it was quite certain that consolidation could not be induced by any method of non-operative treatment. In this way much valuable time was wasted that might have been saved by early operation. Not infrequently, too, the surgeon found on exposing the fractured ends that union without operation had been hopeless from the first. It may safely be said that operation should be had recourse to as a rule much earlier than was formerly the case. It may also be said with fairness that, with the possible exception of operations upon the femur, which are notoriously rather more difficult to keep aseptic, operation adds nothing to the patient's risks in skilful hands, while it diminishes the length of his convalescence.

The following statements fairly represent the present state of surgical opinion:—

(i) All cases should be operated upon without delay that show thin pointed atrophied bone ends and an entire lack of callus a month after the injury. This condition is made out easily with the aid of good stereoscopic radiograms.

(ii) Every case of fracture in which consolidation has not occurred at the end of two months from the receipt of the injury should be submitted to operation provided that there is not progressive improvement made under non-operative measures, and that there is no constitutional disease to contra-indicate it. In the case of the femur this period might be extended to three months, especially in the case of those whose means allow them to be fitted with some form of splint, such as Hoefftcke's, in which they are enabled to walk about freely without having recourse to crutches.

Operation. The steps of the operation resemble those for similar operations in simple fractures (see p. 703), but are much more difficult owing to the contracted condition of the muscles and the alterations that have taken place in the bone ends and the soft parts around.

Complete exposure is the essential for success in these difficult and tedious operations. Without it, it is very difficult to ascertain the exact conditions of affairs and to determine the best treatment to adopt, while the various manipulations necessary to get the bone ends together and fix them are only possible after violence, which causes unnecessary damage to the tissues.

The incision will generally be in the long axis of the bone and on that aspect of the limb where it will involve the least damage to the soft parts, but the determination of the exact seat and number of the incisions can be most satisfactorily arrived at after an inspection of stereoscopic radiograms.

When the seat of fracture has been reached, the soft parts must be separated from the seat of fracture, but in doing this the periosteum should not be detached from the bone. When there is no overlapping of the fractured ends it is not always necessary to clear the soft parts from the deep surface of the fracture. The callus is divided as nearly as possible along the original line of fracture, and the bone ends are prepared for union. The line of fracture is easily made out by moving one fragment upon the other and inserting a knife or chisel between them.

At this stage of the operation two distinct groups of cases may be differentiated. In the first there is simple non-union without displacement, while in the second the non-union has resulted from the displacement. The treatment differs in the two cases.

(*a*) *Simple non-union without displacement.* Here it is obvious that no fixation apparatus is required, since there is no displacement to correct. Therefore it will be sufficient to expose the anterior and lateral surfaces of the fracture only; the posterior aspect can be left undisturbed. These cases are not very satisfactory except in the rare cases in which non-union has followed want of proper immobility during repair. When the fragments are in apposition and are kept on suitable splints and still non-union results, there is generally some constitutional cause at work, and the operation is apt to be followed by non-union also.

The first object in these cases is to remove all soft tissues between the ends of the bone. The next is to refresh the bone surfaces so that active repair may be encouraged. For this a saw is unnecessary; a broad chisel will do. I have found it an excellent plan not to remove the portions of bone thus pared off, but to crush them down firmly into the small gap between the refreshed ends, and I am under the impression that better success is obtained in this way than by simply leaving the refreshed ends in apposition. If the fracture be in the forearm or the leg, and both bones be involved, a similar procedure is carried out in the second bone through a similar incision. If there is any considerable gap left between the ends of the bone after these have been cleared, the autoplastic

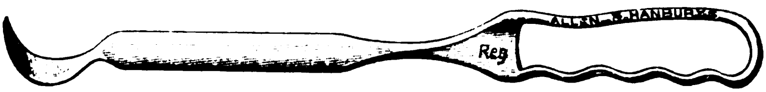


FIG. 286. LANE'S ELEVATOR FOR THE FIXATION OF FRACTURES.

method of bone-grafting (see p. 693) may be applied: a graft is cut off from the affected bone above the seat of fracture, or from another bone, and wedged firmly into the gap.

(*b*) *Non-union accompanied by displacement* of the fragments calls for more elaborate treatment. After the ends have been cleared of soft tissues, they should be sawn so as to fit as accurately to one another as possible. Generally the surfaces of the fracture are oblique, and it may often be possible to fashion a projection in one end to fit a corresponding depression in the other; this is an excellent aid to stability if it can be done, but the limb should not be shortened unduly in order

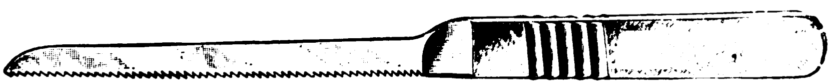


FIG. 287. KEYHOLE SAW FOR BONE.

to obtain it. The sawing may be done *in situ* by a keyhole saw (see Fig. 287) or Gigli's wire saw, but more accurate work will be done by making the incision free enough to turn the ends of the bone out before sawing them. This step also facilitates the application of the fixation apparatus which will always be required in these cases. Fig. 286 shows an excellent instrument for steadying the bones during the manipulations and for getting the ends into due apposition after them.

The chief difficulty in ununited fractures accompanied by displacement is to get the ends of the bones together. The shortening of the muscles and soft parts is of long standing and is very difficult to overcome. Much may be done by persistent and powerful traction exerted by an assistant, accompanied by the division of tight bands that start into relief under the finger as the traction proceeds, though here the greatest care is necessary to avoid damage to important structures. When there is any projecting edge in one fragment to fit into a depression in the other, they may be made to engage by bending the limb at the seat of fracture, hitching one fragment against the other, and then straightening the limb again; this exerts a most powerful leverage, especially in the case of the femur, which generally gives the most trouble. In fractures of this bone in which the fractured surfaces are smooth and oblique and offer no surfaces that can be entangled, a successful result, *i.e.* restoration of the normal line of the bone without any sacrifice in length, is very difficult to attain and many different devices are practised by different surgeons. Thus some have powerful traction exerted by means of pulleys, either fixed to the wall, or, better, forming part of a special operating table. Others use an instrument such as Colt's, in which each fragment is grasped by forceps, and then these are forced apart by a turn-buckle which thus lessens the gap between the ends until these can finally be brought into apposition. Some surgeons do not attempt to restore the limb to its full length in these cases, but merely saw the ends of the bones so as to fit.

In fractures of the leg and forearm, traction will generally suffice to bring the fractured ends into apposition provided that they have been freed before traction is made. The methods of mechanical fixation have been described already (see p. 705), and the surgeon will employ whichever he thinks best adapted to the particular case before him.

Every visible bleeding vessel is ligatured, and any persistent oozing may be stopped by the application of adrenalin. The soft parts are brought together over the seat of fracture by buried sutures of chromicized catgut, the skin is united without a drainage tube, and the limb is immobilized upon a splint.

Operations for mal-union. Indications. (i) The removal of unsightly masses of bone or those causing hindrance to the free use of the limb.

(ii) Fractures that have united with great angular deformity and are both unsightly and crippling owing to the shortening produced.

Operation. In the first group of cases the operation is comparatively simple. The steps of it are merely exposure of the seat of fracture and removal of the offending masses of bone without interfering with the union.

It is in the second group of cases, however, that the surgeon finds the greatest difficulties of all the operations upon fractures. To increase the length of a limb shortened by union of a fracture with great displacement requires great resource, much patience, and considerable strength; sometimes all these qualities fail to attain the object in view.

The fracture, after exposure, must be reproduced by dividing the uniting medium, and it is here that the surgeon will show his resource by making the line of bone section in such a way that the cut surfaces will lock into or rest firmly against one another when they are got into apposition.

Getting the surfaces into apposition may call for much patience and much exertion. The plans already recommended for ununited fracture may be tried, and will probably succeed unless the shortening be very great and the line of fracture very oblique, but it is quite common to have to put up with a certain amount of permanent shortening.

After-treatment. This is the same for all cases. A plaster-of-Paris casing, applied while the patient is still under the anæsthetic and given time to set before he is allowed to come round, will be the best method of securing perfect immobility after the operation. The splint will need interruption to allow of the application of dressings. After the stitches have been removed, a casing can be made to cover the whole limb uninterruptedly.

Results. On the whole these are not so good as theoretical considerations would lead one to expect. It is difficult to give figures, but probably all surgeons of experience in these cases will admit that union is often much delayed after operations for non-union, and in quite a fair proportion may never occur. This is most common in young children, and in the cases characterized by pointed atrophied bone ends and an entire absence of callus. The most untiring efforts may fail in these cases, and amputation be the only alternative. In one case I operated five times by five different methods unsuccessfully as far as union was concerned.

There is some risk of sepsis still attaching to these operations upon the femur even in skilled hands. This, of course, should be a preventable occurrence.

In operations for mal-union the results may also be disappointing, inasmuch as it may be impossible to restore the limb to its normal length, although any angular deformity present before operation may be remedied successfully. Even in these cases, however, the operation may be accompanied by great delay in true bony union, and apparatus may have to be worn for a very considerable period.

SECTION VIII

INJURIES OF JOINTS

BY

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CHAPTER I

GENERAL OUTLINE OF PRINCIPLES

THE fundamental principles of treatment depend on a recognition of the fact that the function of a joint is mechanical, that the processes of repair follow the ordinary physiological laws, and that mechanical injury of the area of repair will retard a cure and often give rise to a state of subacute or chronic inflammation, which may confuse the issue, unless the surgeon clearly understands the condition with which he has to deal. Strain of the inferior calcaneo-scaphoid ligament is an example which should be familiar. After a few days' rest the foot is free from pain, but the first route march brings a return of the trouble, which might have been permanently relieved by a small alteration of the heel of the boot to divert the body weight on to the outer side of the foot, and so save the injured ligament from unnecessary strain until it has fully recovered its strength.

It will therefore be necessary to deal not only with injuries of the joints themselves, but also with those of structures about joints, in order that a clear diagnosis may be made.

The two chief difficulties which seem to trouble most practitioners who have not had the opportunity of handling a large number of joint injuries, are to decide what is the most appropriate immediate treatment, and when and how to commence moving the injured joint, especially after the more serious injuries.

The solution of the first is found in accurate diagnosis of the injury, and in forming a clear idea of the mechanical and physiological factors which enter into the processes of repair. As a simple illustration of this, we will assume that a man jumping from a wall or into a trench lands on the edge of a clod of earth, and violently twists his foot inwards. He feels a sharp stab of pain on the outer side of the ankle, his neighbours perhaps hear a sharp click which makes them think he has broken a bone. By the time the man has limped about and is seen by a surgeon, the whole ankle is swollen and painful. Having excluded a Pott's fracture by running his finger down the fibula and finding it intact, the surgeon makes the diagnosis of 'sprained ankle'. The time-honoured remedy of cold-water bandages or the application of some cooling lotion combined with rest 'till the swelling goes down' is in many cases too frequently adopted; the patient subsequently being allowed up in a soft slipper, which is almost the worst thing he can do in the convalescent stage. Although the ankle is very painful, it will bear gentle but firm handling; the history points to an injury about the external malleolus, and the inference is that there is a rupture of one of the three slips of the external lateral ligament of the ankle, or perhaps an avulsion of a scale of bone from the tip of the malleolus, which is technically a fracture, but for all practical purposes a sprain. Pressure with a finger over each division of the external lateral ligament in turn will find a point of extreme tenderness, and so we locate exactly the injury.

The treatment carried out should be with the definite object of getting the torn ends of the ruptured ligament to unite by first intention, or to

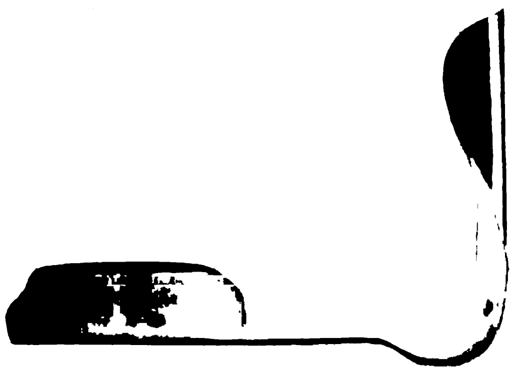

FIG. 288. RECTANGULAR FOOT-SPLINT.

avoid confusion with the terms first and second intention as commonly applied to the history of aseptic and septic wounds, let us say by *immediate* rather than by *delayed* union.

First, the foot should be everted in order to relax the ruptured ligament and bring the torn ends as near each other as possible. Second, avoiding for the present the question of massage, the effusion can be got rid of by firm bandaging over several layers of cotton-wool, the bandages passing not in the orthodox manner from within outwards across the front of the leg, but from *without inwards* so as to keep the foot everted. Third, a rectangular foot-splint should be applied to prevent any recurrence of the ligamentous strain (Fig. 288).

The boot—a comfortable one—should have a couple of wedge-shaped patches of leather put on the heel, base to the outer side, to maintain eversion of the ankle when the patient stands. According to the promptness with which treatment is commenced, all swelling will have disappeared in from twelve to thirty-six hours, with the exception perhaps of a little local swelling round the seat of injury.

It may be advisable in some cases to apply a pad of sticking plaster, sticky side outwards, to fit over the area of injury. This pad should be about three-quarters of an inch wide and half a dozen layers thick; the foot can then be strapped in the everted position, the strapping being applied as a figure-of-eight bandage. This makes an excellent local splint. The united effects of the strapping and the wedge heel make it impossible for him to put tension on the torn ligament when walking. The physiological exercise of the foot will prove a better stimulus to the normal processes of circulation and repair than even the best massage. Provided no strain is allowed at the seat of the injury, in a few days the foot will give no further trouble, in a fortnight he may be fit for full duty, even after a bad sprain. If instead of a boot, he wears a shoe, or still worse, a soft slipper, he is sure to tear the young cicatricial tissue forming between the ends of the torn ligaments, which can then only recover by *delayed* union. Everybody knows that a sprained ankle may make a man lame for many weeks, but the period of incapacity depends largely on the mechanical efficiency of the treatment he receives as well as on the severity of the original lesion.

A rough classification of the injuries of which we propose to treat may be given as follows:

1. **Strains of muscular attachments** about joints often give rise to serious impairment of function. From incomplete diagnosis these conditions are often inefficiently treated. They are diagnosed by the fact that there are certain movements which the patient cannot perform because he is suddenly pulled up by pain, which he localizes fairly exactly at some point about a joint. Careful testing of the movement which hurts will generally prove that active contraction against resistance, or passive stretching of a certain group of muscles, causes the pain. Further careful palpation will find a tender spot just at the attachment of a tendon, over an area perhaps no bigger than a sixpence, and a little swelling with a suggestion of œdema or fluid may be felt deep down on the surface of the bone. This tender spot is the key to the situation. It is a small patch of effusion below the periosteum or in the fibres of the tendon which run in and through the periosteum to the bone, constituting the origin or insertion of the muscle.

The pain is due to tension on this effusion caused by tension on the muscle or by direct pressure on the œdematous spot.

Such an injury may be acute in type, arising from a single sudden wrench, stretching, tearing, or otherwise loosening the strong fibro-tendinous plexus; it may be subacute, arising from repeated smaller injuries, as in the familiar 'tennis' and 'golf' elbows; or either of these may pass on to a chronic stage, never entirely dormant, and liable to become more acute on any provocation, and this chronic stage may continue for weeks, disabling the patient from taking part in active pursuits. The reason why this trifling injury is often so long continued and troublesome is that every time tension is put on the muscle a fresh assault is inflicted on the injured tissues, and this repeated injury maintains the effusion and prevents repair of the stretched or torn fibrils.

Treatment should therefore be directed definitely, first, towards getting rid of the effusion which separates the torn ends of tissues and so allowing them to come into their proper position; second, towards preventing any movement or muscular effort from stretching and tearing the newly formed repair tissue and so making the condition chronic.

This may be done (*a*) by firm pressure with a folded pad of sticking plaster strapped over the area of effusion to promote its absorption and to act as a local splint on the injured fibres; (*b*) by a similar pad and strap placed on the tendon just above the inflamed area; this acts as a stop, preventing the tension on the muscle from being transmitted in its full force to the injured attachment. This is comparable to the half-turn round a post which a sailor takes with a rope when he wishes to check a movement which he could not stop by the direct application of his strength. This is no new principle, although sadly overlooked by the profession, for every workman who puts a strap around his wrist to ease a strained tendon is putting it into practice. The wonder is that so few surgeons apply it to the deltoid, the quadriceps extensor, the ankle and the foot, as well as to the wrist.

We often have to deal with the chronic case. Here the trouble is that repeated small injuries with repeated efforts at repair have produced a small plexus of new fibrous tissue, which itself impedes the free access of blood necessary for the complete removal of effusion and the conclusion of the processes of repair.

Treatment must then be directed to encouraging a free flow of blood to and through the injured area. This is not effected by a passive congestion, but by massage and alternate applications of hot and cold water, by counter-irritation, and in obstinate cases, where the pain is confined to a very limited area, by puncture with a heated needle, which both destroys implicated nerve-ends and produces an increased flow of blood.

2. **Sprains of ligaments,** that is, rupture of fibres of ligaments.

This injury may occur anywhere in the extent of the ligament, either at one of its attachments or in the body of the ligament. All the general remarks about the nature of the processes at work made in the previous section apply to these injuries.

First localize the injury accurately, then reduce effusion, and finally prevent repetition of the injury by preventing mechanical strain.

The above two classes of injury should invariably end in recovery without any impairment of movement, the time occupied depending largely on the efficiency of the immediate treatment.

In the more severe types of injury stiffness or ankylosis may arise as a result of efforts at repair. In such cases there must be added to the immediate treatment to secure repair of injured tissues, a carefully considered scheme of after-treatment to restore freedom of movement.

3. **Extensive rupture of ligaments, including dislocation.** In cases of dislocation, obviously, *reduction* of the *displacement* is the first consideration. Next, the joint must be left at rest to allow repair of the extensively torn soft tissue. This repair means a considerable deposit of new fibrous tissue. Short strong bands of fibrous tissue about a joint which impede freedom of movement are spoken of as 'adhesions', and a time may come when it is necessary to break down these adhesions. It is important to know the right time for doing this. It is unfortunate that in many text-books of surgery the phrase 'early passive movement' has been employed without clearly defining the limits of its usefulness. This is not really difficult if due regard is paid to the histological processes of repair. Take, for example, a posterior dislocation of the elbow without any fracture complications. The dislocation has been reduced and the elbow put in an acutely flexed position to relax the torn anterior ligaments. Between and about the torn ends of the ligaments there is a mass of blood-clot and plastic effusion, part of which will be absorbed and become organized by the ingrowth of blood-vessels and fibroblasts laying down new strands of white fibrous tissue. If we could see this a few days later, the whole area would be a vascular mass, corresponding to the stage of granulations of a surface wound, and, like the surface wound, tender to finger pressure. This tenderness to pressure is an important index, for it means that the cicatrix is still so fresh and vascular that any attempt at passive extension will tear the new tissue, cause pain, more bleeding, and more effusion, the repair of which means a more dense fibrous cicatrix than is desirable, resulting in unnecessarily strong adhesions.

If the surgeon restrains himself and leaves the movement to the patient, in the case of the elbow, slackening the sling each day so that the wrist falls a little lower, but on no occasion so far as to tear the cicatrix, and allows the patient to flex and extend his elbow within the limits allowed by the sling, *without pain,* then we may expect local tenderness to die away, and a natural recovery to take place.

This process of recovery may be expedited by a judicious exercise of passive movement. The joint should be gently moved through its complete range of movement, and rested until it recovers from the assault. The object is to release the joint from obstructing bands, and this must be done in such a way as to minimize reaction. *Once* and *once only* should it be flexed, extended, pronated, and supinated at each manipulation. This can be repeated each day or at longer intervals according to the degree of reaction produced. The to-and-fro oft-repeated method must be utterly condemned.

We should never add the injury caused by passive movement to an existing active state of reparative inflammation, but wait till the reparative action has quieted down. If the patient's range of voluntary movement the day after passive movement is less than before, it is a clear indication that the joint is still too actively inflamed to undergo passive movement. If after passive movement the pain is less and the range of movement is greater than before, it is safe to go on with both active and passive movement.

4. **Injuries of joints associated with fracture,** either into the joint or so near the joint as to affect the proper relation of the joint surface to the line of the limb, and compound injuries including gunshot wounds, which smash bones as well as tear soft parts, introduce new complications, which must be foreseen and as far as possible guarded against by anticipatory treatment. Fragments of bone or masses of new-formed callus may form a mechanical obstruction to movement. A most conspicuous example of this is to be found in the front of the elbow, where a block of bone may obstruct flexion. This danger is obviated by fixing the elbow in the fully flexed position.

In cases of fracture into the joint or bullet-wounds which have destroyed the joint cartilages, some degree of repair tissue may be formed between the two bones. If this repair tissue remains fibrous, a good functional joint may be secured by treatment which will be referred to later. If this repair tissue should ossify, absolute ankylosis will result, and may call for operation. When bony ankylosis is foreseen as inevitable, the surgeon must decide in what position the joint is to be allowed to ankylose, so as to obtain the best possible function for the limb.

In the upper limb the use of a knife and fork, the difficulties associated with collar-studs and dressing the hair, and manifold other considerations, help us to decide the question, while in the lower limb we desire a firm support for walking with a minimum of limp.

The question of an operation to form a false joint does not arise in the first instance; it is only to be considered when the result of the original treatment has ended in an intolerable condition, and then the patient must help us to decide.

CHAPTER II

BANDAGING, MASSAGE, MOVEMENT

Direction of bandaging. The traditional teaching of bandaging ' from within outwards over the front of the limb ', however useful as a means of training students to obtain dexterity in handling bandages, must be abandoned when treating joints. The bandage in the hands of the surgeon is an important part of the apparatus for retaining the joint in the required position. The bandage is not a mere means of keeping a dressing in position, but should be regarded as a modified splint.

As a general rule the figure of eight is essential about joints, and the position of crossing important. For example, in bandaging a knee to support a strained internal lateral ligament, the bandage should be applied so as to check any abduction movement of the joint and so prevent tension on the injured ligament; therefore a thin pad of wool should be placed over the injured ligament, and the bandages should cross to and fro over this pad. The crossings of the bandage would press on the inner side of the knee, and the upper and lower loops of the eight would tend to pull the thigh and leg towards it and so keep the internal ligament relaxed.

To keep the foot everted at the ankle and relax the external ligament, the bandage would cross the sole from within outwards and the front of the leg from without inwards; the draw of the bandage as it is put on pulls the outer edge of the sole up towards the external malleolus, and the crossing would be kept well to the outer side. To relax the internal ligament, every movement would be in the reverse direction.

Bandages of calico are more efficient than flannel or domette, for the woollen materials stretch too much to produce an efficient grip of the limb.

Elastic pressure. Elastic pressure, to check bleeding or promote absorption without interfering with the general circulation of the limb, can be obtained by using large quantities of cotton-wool, and is best done as follows: first swathe the part in wool and bandage firmly over this, taking care that the bandage is running in the right direction to maintain the desired position. Then apply more sheets of cotton-wool and continue the bandaging rather tighter than the first layer, and so on, layer after layer, each put on tighter than the former. As the swelling goes down the bandages will become loose. Do not disturb the joint by removing the bandage, but keep up the pressure by an additional bandage over everything. This can be removed and reapplied as often as necessary without moving the joint or disturbing the position of the wool padding. The more wool is used the tighter can the bandage be applied without fear of doing harm or hurting the patient.

Massage. It should be clearly understood that massage of a joint does not include movement. A masseur who will not massage without moving a joint will often do more harm than good, because he disturbs tissues which should be left at rest to undergo repair.

1. Massage immediately after the injury, before effusion has taken place, checks hæmorrhage into the part, stops effusion of lymph, relieves pain, and so leaves the tissues ready to commence immediate union, like a clean cut which is immediately closed edge to edge.

As an illustrative example, take once more rupture of the anterior division of the external lateral ligament of the ankle-joint. Immediately after the injury, when the boot is removed, there may be a swelling below and in front of the malleolus as big as a pigeon's egg. If vibratory massage is at once given by pressing the pulps of all the fingers firmly on this and communicating a firm vibratory movement from the wrist, this swelling will disappear in a few minutes. A small pad and a firm bandage to evert the foot is then applied, and the patient can walk home without any great swelling round the ankle. The art of vibrating is of course only to be acquired by practice, and is a muscular effort on the part of the masseur, which soon becomes very fatiguing, hence the numerous mechanical vibrators on the market.

If the patient has to hobble home without this immediate treatment, the whole region of the joint is so swollen that much valuable time may be lost in getting rid of the effusion before the tissues can really set about the process of repair.

2. Once general swelling has made its appearance, the joint should be put in such a position that the injured tissues are relaxed, and gentle rubbing in the direction of the venous circulation will help to get rid of the effusion. If there is any fear of doing harm by inadvertently moving the joint, it is better to rely entirely on elastic pressure and rest and elevating the limb to hasten absorption of exudates.

3. Massage of muscles, by gentle deep kneading, by stroking, and by gentle pinching and rolling between the fingers, is of great assistance in maintaining the nutrition and circulation of a limb when the nature of the injury demands prolonged fixation, but it must be done without moving any part undergoing the process of repair. Anything which improves nutrition aids repair.

4. Deep-pressure massage with coarse vibration, followed by firm rubbing, is of great service in promoting circulation in masses of cicatricial tissue resulting from the repair of severe injuries. Dense fibrous tissue is not elastic, hence the blood-vessels in it cannot expand easily in response to changes of pressure. Patients with such cicatrices complain of 'rheumatic' pains; these are probably due to the same cause as shooting pains in corns when a fall in the barometer precedes a thunderstorm, and are entirely due to imperfect adjustment of blood-pressure. Massage not only relieves this pain temporarily, but helps to induce more elasticity and better circulation in the cicatricial masses.

Movement. Movement is always bad for an actively inflamed tissue—by 'inflamed' we mean a tissue that is actively hyperæmic as the result of a lesion, and not in the narrow sense of septic inflammation, and for the present purposes we include the active hyperæmia, which is part of the process of healthy repair.

Movement is of three kinds:

1. Involuntary reflex movement.
2. Voluntary movement.
3. Passive movement.

1. **Involuntary reflex movement** should be controlled by efficient fixation. When a patient with an injured bone or joint is awake, and the injured part is not completely fixed, he unconsciously keeps it at rest by means of his muscles. This muscular guard is a nerve-muscle effort, and is itself exhausting to the patient. When the patient falls asleep nervous and muscular systems sleep also; the injured part deprived of the muscular guard moves, there is a spasm of pain, a reflex contraction of the muscles, which again causes pain, and the patient is awake. This ought to be prevented by proper fixation, for pain, loss of sleep, and constant muscular action, even though unconscious or subconscious, are all exhausting.

2. **Voluntary movement** is the natural physiological function of muscles and joints, and is the best physiological stimulus to their proper nutrition and well-being. Pain is nature's method of controlling voluntary movement which may be harmful, and the exceptions to this rule are very few. Hence early active movement which causes no pain can seldom be harmful, and is often beneficial. This can often be obtained by fixing a joint so that one particular harmful movement cannot be performed—all harmless movements being but little impeded. This makes for good nutrition and rapid repair.

3. **Passive movement** being performed by a second person, regardless of warnings by pain, should never be resorted to unless the surgeon knows exactly what he wants to do and why. It should practically be

limited to forcing a free path for movements which are obstructed by adhesions. When adhesions are thus broken down under an anæsthetic the process should be thorough, and if possible, carried out by one firm movement. I would again emphasize the fact that repeated to-and-fro movements are liable to cause unnecessary damage, increased reaction and effusion, and an increase of pain. Having broken down adhesions, it should be sufficient to put the joint through its full range of movement once a day, and once only, until the patient can perform the movement voluntarily.

CHAPTER III

PAIN AND STIFFNESS IN RELATION TO DIAGNOSIS AND TREATMENT

Pain and stiffness in and about joints are valuable aids to diagnosis and treatment.

In cases of recent injury about joints, where the whole region of the joint is swollen, the patient very often complains that the whole joint aches, and says that he cannot bear it to be touched.

If the surgeon approaches the case gently he should be able to determine at once whether the injury is a serious one of the joint itself, or merely some less important injury of structure outside the joint.

To do this it is necessary to avoid hurting the patient, because then the muscular resistance excited by the pain will make further accurate examination very difficult. An injured joint resents any sudden jar or jolt, and when there is effusion in the cavity of the joint, any movement of it may raise the tension, and thus cause pain.

The hands should therefore first be laid on the limb above and below the joint very gently. If the history of the injury suggests that it is most likely a rupture of some ligament, the hands can be passed gently over the joint, feeling for some point of acute tenderness over the ruptured ligament. Next the limb may be held firmly above and below the joint and very gently moved.

Localized pain. If it is found that some movements—those which do not put tension on the suspected ligament—do not cause much pain, and are not strongly resisted, while the least movement in the direction which stretches the suspected ligament is immediately resisted and causes sharp pain in the region which was found to be most tender to touch, it will be pretty clear that the injury is located to one structure or group of structures, muscular or ligamentous, on one side of the joint. The surgeon has then a guide to help him to decide in what position he is to place the limb, and he can confirm his diagnosis later when the swelling and first tenderness have passed off.

The diagnosis of severe joint lesions is often obscured by swelling, and, indeed, in many very serious injuries involving bone and ligaments, bony deformity may be entirely masked. The surgeon should at once be put on his guard by the fact that any movement of the joint is at once resisted and causes pain. We therefore get a rule of guidance:

1. Pain on movement in every direction suggests a lesion in the joint or in parts intimately connected with it.

2. Freedom of movement in one or more directions, but not in all, suggests a lesion of some groups of structures outside the joint proper.

Pain due to contusion of joint cartilage may not make its appearance until two or three weeks after the accident. This condition is not described in text-books. It occurs in a very typical form in the shoulder-joint in association with Colles's fracture of the lower end of the radius. A patient falls heavily on the hand and sustains a Colles's fracture. The fracture is treated, but no complaint is made of the shoulder. A fortnight or three weeks later, when the fracture is getting better, and greater freedom of the limb is allowed, the patient experiences pain when he tries to move the shoulder. He considers this due to stiffness, and goes on moving his shoulder, and soon both pain and stiffness become worse. The doctor too often tries passive movement, and the shoulder gets still worse. A vague diagnosis of 'rheumatism' is often made, and later the patient, failing to obtain relief, does nothing, and in three or more months his shoulder recovers. What has really happened is that at the time when he fell on his hand he bruised or crushed the shoulder-joint cartilage. Cartilage, like the cornea, is a non-vascular structure. When the cornea is injured, no repair can take place till a little leash of new vessels grows in from the nearest part of the sclerotic. When repair is complete, these vessels disappear, leaving a fine hair streak leading from the sclerotic to the nebula, which is the cicatrix at the seat of injury.

Much the same process occurs in an injured joint cartilage. The débris of crushed cells and cartilaginous tissue cannot be cleared away till new vessels have grown in, constituting a process of reparative inflammation. In the injury of the shoulder associated with a Colles's fracture, this process starts while the patient has his arm in a sling, and goes on quietly without his knowledge. At the end of a fortnight or so the vascularization of the cartilage is active, and the effect of movement is to rub the inflamed cartilage and add to the pre-existing injury, consequently the result of movement is that there is more pain.

The seat of the inflamed area is within the joint, and movement is limited and resented in every direction.

Rules. I will formulate certain rules which may be helpful in deciding whether to move a joint or not.

(*a*) A joint may be assumed to be free from arthritis when even one of its movements is free.

(*b*) Traumatic arthritis follows an injury after an interval of free movement, lasting usually over a fortnight.

(*c*) Restricted movements due to adhesions are noticed very shortly after the occurrence of injury.

(*d*) Except when following serious injuries, adhesions restrict the movements of joints in one or more, but not in all directions.

(*e*) A joint, the seat of arthritis, should not be moved until all inflammatory symptoms have subsided.

(*f*) If adhesions are broken down under an anæsthetic, the joint should be put through its complete range of movement, otherwise a recurrence of symptoms may be expected.

Pain in cicatrices. Pain at the site of a healed injury is often very confusing to the practitioner. Very often after an injury due to violence, repair is only accomplished by the formation of a considerable mass of cicatricial tissue. If there has been a suppurative wound associated with much bruising and tearing of the soft parts, as in a shrapnel or bullet wound which has driven shattered bone through the soft parts, there must be for a long time a mass of cicatricial tissue in the deeper parts of the wound, often out of proportion to the size of the surface wound of entry.

After the sepsis has been overcome and the wound has healed, these cicatrized areas remain tender; shooting pains are felt, and are sometimes called neuritis, though there is no real inflammation of the nerve: often the pain passes off when the patient uses the limb, but reappears at night; such cicatricial areas are also sensitive to changes of atmospheric pressure. Pain of this type is generally due to irregularities of blood-pressure. If such an area were superficial it would be a dusky scar, obviously the seat of venous congestion, and the treatment would be to promote vascular activity. To test this in deeply situated cicatrices about joints, all that is necessary is to promote a rapid flow of blood to the surface by lightly slapping and massaging the skin; as soon as a rosy flush appears on the skin, ask the patient to move the joint, and if he can do so with less pain and stiffness than before it will be obvious that the slight alteration in blood-pressure has made all the difference.

The treatment advised will therefore be:

(*a*) To use the limb with tolerable freedom.

(*b*) To assist the restoration of free circulation by deep massage.

(*c*) To relieve pain at night, by hot applications to the surface, so that the patient may have longer periods of undisturbed sleep.

Electricity, especially high frequency current and diathermy, and also hot-air baths and radiant heat, relieve pain of this type, but in all cases the venous congestion and pain return as the limb cools down.

As these measures are often not available, a very simple remedy which is always accessible may be substituted, namely:

Contrast baths. Contrast bathing with hot and cold water. Two buckets are required, one with the hottest water the patient can bear, and the other with the coldest that can be procured. In the case of a foot or wrist the injured limb is plunged first into the one and then into the other as fast as the patient can change them for five or ten minutes; in other parts two sponges may be used, one for hot and one for cold water. The effect is to cause the small vessels to dilate and contract rapidly. The treatment thus acts as a species of gymnastics for the muscles in the vascular walls. Besides relieving the pain the result is an improvement in the physiological efficiency of the tissues at fault. This is not achieved to anything like the same extent by hot air and the various electric treatments.

CHAPTER IV

STIFFNESS AND LIMITATION OF MOVEMENT

STIFFNESS and limitation of movement may be due to several different causes; and the type, significance, and treatment vary accordingly.

First there is a stiffness or limitation of movement due to muscular resistance which is associated with pain, the result of some inflammatory or traumatic lesion. Such stiffness is a natural physiological phenomenon; it has been referred to already in the discussion on the meaning of pain, and needs no further mention beyond a reminder that limitation of every movement of a joint is an indication of arthritis or of a serious injury of the joint, while limitation of only certain movements indicates only a local lesion, most probably outside the joint.

Next there is stiffness, or limitation of movement which we may call mechanical in origin, due to fibrous adhesions, to blocking of the range of movement by fragments of bone or deposits of callus, and in the extreme case it may be due to bony ankylosis.

1. Fibrous adhesions about a joint are the result of cicatrix formation after trauma or an inflammatory lesion. Enough has already been said of the danger of increasing the amount of cicatricial tissue by injudicious passive movement too early in the course of repair.

On the other hand, too prolonged fixation gives the newly formed cicatrix time to stiffen, but this is the lesser of the two evils. When the local effusion and tenderness abate, the patient may be allowed to commence gentle active movements. He is not likely to carry these out sufficiently roughly to tear or damage newly formed scar tissue, because pain will act as a check.

On passive movement, a joint with fibrous adhesions conveys a characteristic sensation to the hands of the surgeon, which differs on the one hand from muscular resistance associated with pain, and the abrupt blocking of movement caused by a bony obstruction on the other. The cessation of movement is definite and unmistakable, but it is not associated with pain, unless the surgeon exerts a little force to put tension on the fibrous band. If in any doubt whether there is disease of the osseous elements of the joint, an X-ray photograph should be taken, when the clear structure of the bone, smooth and even contours of the joint surfaces, and the absence of blotched or cloudy patches in and about the ends of the bone, will definitely exclude active disease.

ON THE BREAKING DOWN OF ADHESIONS

The treatment then is to break down the adhesions under full anæsthesia to relax all muscular resistance, gas is not sufficient. It is no use making half-hearted attempts; these only give rise to effusion and increased stiffness. Every resisting band must be stretched or ruptured by steadily continued and increasing tension. Sudden jerking movements must be avoided because (*a*) they are inefficient, (*b*) they cause unnecessary irritation of the tissues and unnecessary effusion, (*c*) they may break a bone instead of rupturing the fibrous band.

In the case of the shoulder the arm is first abducted, care being taken not to strain the joint by over-abduction. An essential rule, especially in old people, is to control the manipulation by a comparison with the sound arm, as considerable variations in the range of movements are to be noted in different individuals. An assistant should fix the scapula and, with his fist in the axilla, put pressure upon the head of the humerus to prevent dislocation. First with the arm lying at the side of the chest, and afterwards in the position of abduction, the humerus should be rotated inwards and outwards. This movement should be performed very slowly and yet very thoroughly. It is the movement most likely to cause fracture near the joint. The last and most frequently neglected movement is that of forcing the elbow back while the arm is fully abducted. During all these movements, the scapula is fixed. It should now be released and allowed to participate in the complete elevation and abduction of the limb, lest it should have formed adhesions separately from those about the joint.

The same principles apply in breaking down adhesions of other joints. In the case of the elbow, if the adhesions are tough, care must be taken not to produce a fracture. In such an instance, it is a good practice to protect the humerus and bones of the forearm by applying splints of sheet metal above and below the elbow. It will then be practically impossible to produce a fracture excepting at the olecranon, which has to be carefully guarded.

The most striking results are often brought about in the case of the knee, if we remember one very important point, and that is, to secure the full rotatory range. If we confine ourselves to ordinary flexion and extension, we miss those cases of adhesions which follow displacements of the semilunar cartilage and injuries to the internal lateral ligament. In breaking down adhesions in the knee to correct the stiffness following fracture of the lower end of the femur, the thigh should be carefully splinted, as the bone may easily be fractured again even after several months.

After adhesions have been broken down, the treatment should consist of massage and both passive and active movements. The passive movements should be carefully regulated, the active should be unlimited. As soon as the patient has sufficiently recovered from the anæsthetic, he should be put through all his movements. He will then be convinced of the freedom of the joint and this will prove a valuable asset towards recovery.

Blocking of movement by bony obstructions may be due to many causes, such as:

(*a*) Myositis ossificans traumatica, which is peculiarly associated with dislocations of the elbow, will be dealt with when discussing injuries of the elbow.

(*b*) Fragments of fractured bone, or even a projecting end of bone in an uncomplicated fracture about a joint.

(*c*) Excessive formation of callus near a joint.

(*d*) Unreduced dislocations.

The occurrence of myositis ossificans can neither be foreseen nor prevented, but the other conditions can be foreseen, and ought to be prevented; though in septic compound wounds, such as occur in the present war, failure is sometimes inevitable. It is, however, all the more important to understand the difficulties and the means of meeting them, for it is only in the earlier stages of treatment that the obstruction can be dealt with easily.

Obstruction of movement of a joint by a projecting end of fractured bone occurs most frequently in fractures about the condyles of the humerus. It is the lower end of the upper fragment which usually projects forwards. This is entirely due to imperfect reduction of the displaced fragments. It should be prevented by proper complete reduction in the first instance. If, for any reason, the lower fragment slips back during treatment, it should be again brought forward before the callus is too hard to be forced.

So long as callus is tender on pressure or manipulation, it is safe to say it is not too hard to be twisted or forced by manipulation so as to adjust an erroneous or imperfect reduction.

Passive movement is undesirable in the stage of repair during which the seat of a fracture is still vascular and tender, and not consolidated, and therefore permits of forcible readjustment of the position of the fragments of bone; this corresponds to the tender vascular stage in the cicatrization of soft parts. So, just as tearing the soft cicatrix means more effusion and excessive cicatricial tissue, the necessity forcibly to twist or readjust callus after it has begun to form carries with it the penalty that the increase of exudate may result in excessive formation of bony callus. Small displaced fragments should not be left where they will obstruct the movement of the joint. The ideal treatment is to get them back into their place. A common example where this can be done is found in the fracture of the anterior edge of the lower articular surface of the tibia, which often occurs in association with Pott's fracture of the fibula. All that is here needed is to dorsiflex the foot when setting the fracture; the surgeon then pushes the wedge-shaped piece of bone back into position, where it is held by keeping the foot dorsiflexed.

At the elbow fragments of the bone blocking full flexion will usually be pushed aside when putting the joint into full flexion. If the fragment will not get out of the way, there should be no hesitation about readjusting or removing it by operation.

The formation of excessive callus, *i.e.* excessive osseous formation in the exudates of blood and lymph about the seat of injury, may be determined by the violence of the original injury, which of course is beyond the surgeon's control, but is often due to unnecessary irritation of exudate at a later stage by imperfect fixation, by allowing injudicious movements, or by unwise attempts at passive movement before the callus is firm enough to withstand them. Everything that has been said about the dangers of too early or too rough passive movement in connexion with fibrous cicatrices in soft parts applies much more strongly where the process of repair includes ossification, for fibrous bands can generally be stretched or ruptured if necessary, but osseous formations are not so easily disposed of when once they are fully formed.

It is a physical law that matter occupies space; therefore, if no space is left in which excessive callus may form, it cannot be formed. This method of meeting the difficulty can be employed at the elbow, for if the joint is fully flexed during treatment of a smash about the condyles, no excess of callus can form in front to block flexion; behind, the broad tendon of the triceps serves the same purpose. The only exception to this rule of full flexion in elbow injuries is when the olecranon is fractured.

Ankylosis may be fibrous or osseous, and is a serious menace to movement. It arises when the cartilaginous surfaces of the joint have been injured, leaving raw surfaces between which repair tissue may be formed.

This repair tissue may only go the length of fibrous tissue; by judicious exercise this may gradually stretch and a reasonably useful joint result. Attempts at violent stretching or rupture of the fibrous tissues connecting the joint surfaces are generally to be regarded as injudicious, because they excite increased exudate which forms a basis for more cicatricial tissue, and also because violent handling may excite the bone cells communicating with the joint through the injured cartilage to activity, and then the osteogenetic cells will invade the area of exudate and produce osseous repair.

Hence, in a case of fracture into a joint, or of a bullet having traversed the joint and ploughed up the osseous cartilages, the line of treatment must be directed towards obtaining healing of the breach of surface on each bone separately, and allowing the union from one to the other to be as slight as possible. When sufficient time has elapsed for repair to have commenced, slight movements should be allowed. These should be such movements as would tend to produce non-union in the fracture of the shaft of a long bone. Part of the treatment of ununited fracture of a long bone is to manipulate the seat of fracture roughly, so as to produce fresh exudation and vascular activity and to excite osteogenetic processes. It is therefore obvious that violent movements of a joint, instead of securing non-union between opposing surfaces, may have the opposite effect.

When bony ankylosis is seen to be inevitable, or is seriously to be feared, the position in which the limb is placed during treatment is of great importance. The guiding factor is the function of the limb.

In the upper limb, usefulness of the hand is of first importance, and treatment is planned accordingly. A limb with an ankylosed joint may still be very useful.

In the lower limb, weight-carrying and locomotion demand stability, and this must guide the surgeon. In injuries about the vertebræ, the object is to preserve the erect attitude, because the spine must carry the weight of head and shoulders. If a hunch back is once formed by yielding at the seat of injury, the weight of head and shoulders will tend to increase the deformity.

Neurotic stiffness of joints. It frequently happens that after some injury which has caused a considerable amount of pain, stiffness of the joint persists long after local repair is complete, without any mechanical cause being apparent.

These cases are among the so-called cases of neurotic or hysterical joints. They really depend on a persistence of the habit of keeping the joint still which was acquired during the stage of acute painfulness. The fault is often in the patient, sometimes the surgeon must share the blame. An instance of the latter state of affairs came under the author's notice about two years ago. A boy injured his knee: the doctor very properly fixed it on a straight splint till all pain and swelling had disappeared. He so strongly impressed on the mind of the boy and his mother that he must not move the knee or he might have a relapse, that more than a year later the boy appeared in hospital suffering from a 'stiff' knee.

Practical demonstration that the knee was not really stiff by moving it through a small angle greater than the boy had accomplished since his accident, and insisting that he should himself do so voluntarily, followed by drill in moving the joint, effectively obliterated the memory or suggestion or hysteria that the joint could not be moved. These cases are just as likely to occur among the young and athletic as among the feeble and debilitated. The surgeon should never forget that they may occur, and should be particularly careful to distinguish them from cases of malingering. The latter is a conscious effort to simulate disease, and is usually clumsy and easily detected; but a neurotic joint is accurate in its simulation, because it depends on a persistence of the reflex nerve-muscle guard of an injured area after the real pathological condition which excited the reflex has ceased to exist. There always has been a genuine cause for these cases; it may be only slight, but nevertheless real. The higher conscious nervous system has failed to take control of the situation; the case is one for education, not punishment.

CHAPTER V

ON CONTRACTION OF SCAR TISSUE AND COMPOUND INJURIES ABOUT JOINTS

THE behaviour of large and deep scars has been studied mainly in connexion with bruises and burns. In the present war there have been a large number of extensive wounds from shell fire and compound wounds of bones and joints with large exit wounds. Moreover, there has been added a great deal of phlegmonous and gangrenous change in the tissues, leading to considerable loss of tissue. There has, therefore, in the last nine months been ample opportunity of applying the lessons learned in civil practice and to test their truth.

It is necessary to take a brief view of the histological changes going on at the site of the wound, and to see how they are to be controlled in order to prevent stiffness of joints and mechanical disabilities due to the contracting scar.

Roughly one may divide the process of repair, whether in epithelium, connective tissues generally, or bone in particular, into three stages.

First: Early repair processes include the removal of dead tissues, sloughs, and necroses, and the establishment of an active hyperæmia with the formation of new loops of blood-vessels permeating the mass of blood-clot, exudate, and damaged tissues. In a surface wound this includes all stages up to the establishment of granulation tissue.

Second: The second stage is that of immaturely formed repair elements, especially the laying down of fibrous tissue elements and bone elements to form cicatrix and callus. In this stage the seat of injury is still hyperæmic, but as the formed elements mature, the vascularity gradually diminishes, and the whole seat of repair passes gradually into the third stage.

Third: The mature scar consists of fully formed fibrous tissue elements and hard callus. The fibrous tissue has become white owing to the disappearance of active hyperæmia, and in some cases, owing to contraction of fibrous tissue, repair of other parts of the wound is impeded for want of blood.

About joints—say, the front of the wrist, the back of the knee, the flexure of the elbow—there is a great tendency for the new scar to go on contracting till the limb is fixed in a useless, flexed position. Owing to the contraction of the scar, the blood-vessels cannot expand freely, and the whole area becomes dense, white, and anæmic.

The first stage: during the first stage the region of the wound or injury must be left very much at rest. Fractures should be put up in the best position, torn tissues brought together as far as possible, and then left for the new repair blood-vessels to grow between fragments. These grow in the plastic exudate; therefore any rough handling, injudicious massage or movement, will only tear them.

Free exit must be given to all discharges in septic cases, that the tissues may be as little as possible sodden in poisonous toxins and as much as possible nourished and fortified by the food elements and antibodies in the blood fluids.

Therefore the surgeon should at once decide in what position the limb is to be treated, and endeavour not to move it until repair is well established.

In the second stage: passive movement is apt to tear newly formed tissues, causing bleeding and increased organization of scar tissue. On the other hand, it is possible now gently and gradually to change the position of the limb.

It is during the end of this stage, when the immature tissue elements are becoming matured, that the tendency to contract takes place; therefore if the limb has not already been put in the position opposed to the deformity which is feared, it should be done now.

For example: in a bullet-wound through the condyles of the humerus, with extensive loss of tissue and suppuration in front of the elbow, there will be a large scar formation.

First, the fracture must be reduced, the arm put in the flexed position, and free drainage and dressing provided for.

Next, as soon as the bone becomes fixed the elbow should be placed at a less acute angle, and as soon as possible in the extension splint shown on the diagram (Figs. 298 and 299). All this stage of treatment should be completed before the contraction of the new fibrous tissue shows itself.

Next, as soon as the union of the bone is firm enough the surgeon should risk straining the callus a little by getting the arm out to full extension and allow epitheliation to take place in this position.

In such a case there will be a large granulating surface with epithelium growing in from the side. The granulations in the centre are apt to become heaped up and excessive; this should be prevented by pruning them down with scissors or even scraping them away with a sharp spoon.

The more the granulations, the bigger the mass of organized fibrous tissue formed, and the more trouble from contraction.

Skin-grafting is not to be relied on to do away with the contractility of the underlying scar tissue. Therefore the elbow should be kept fully extended till epitheliation is complete, and the new fibrous tissue has

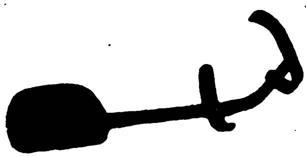

FIG. 289. SHORT HAND SPLINT.

become adapted to the extended position, and has no longer a vicious tendency to contract.

Rules. So far as possible, having regard to fractures, the following rules should be observed:

(*a*) The strong muscles in the axillary fold when torn by shrapnel must not be allowed to heal with a short stiff scar. Therefore the arm should be abducted.

(*b*) Wounds in the flexure of the elbow should be treated with the elbow extended.

(*c*) Burns and septic wounds of the front of the wrist and palm of the hands and fingers must be treated in hyperextension. The splint shown in diagram will be found useful (Figs. 289 and 290).

FIG. 290. SHORT HAND SPLINT. *Applied.*

(*d*) For wounds in the flexure of the hip, the thigh should be in line with the body and a little abducted.

(*e*) In wounds in the back of the thigh the knee should be kept straight.

(*f*) The foot must in any case be kept at right angles to the leg.

Third stage: when wounds have already reached the contracting or fully contracted state they are not hopeless.

Continuous extension on a splint will make the scar tissue yield: daily passive stretching is of comparatively little value, for the fibrous tissue is only irritated and contracts all the more in the intervals. The extension, therefore, must be continuous. As the moorings of the scar become stretched the thin glazed epithelium over it shrinks, and the healthy surrounding skin becomes loose and stretches towards the scar, and so in time with *continuous* stretching, aided by massage, many of the most stubborn contractions, such as occur after deep burns, can be overcome and made supple.

The moral, however, is that although it may take a little longer for the wound to get covered with epithelium, it saves time and an infinity of trouble to put the limb in the stretched position at once or as early in the second stage of repair as possible.

Further, prevent excessive formation of fibrous tissue by pruning down excessive granulations. Granulations consist of loops of new capillaries, and it is along the walls of these that the fibroblasts lay down new fibrous tissue.

Fully matured fibrous tissue has no more tendency to contract than any other tissue, and as a scar takes a long time to become composed of fully mature tissue, extension of the scar must be prolonged.

The author has by steady stretching alone obtained good mobile wrists and hands in cases which had been crippled by contraction after burns for several years.

ISCHÆMIC PARALYSIS

Ischæmic paralysis of the hand is a condition sometimes associated with fractures of the upper limb, chiefly about the elbow and upper forearm.

It is often associated with tight bandaging, but the paralysis may also be due to pressure from within the arm. The pressure of the broken ends of bone, the tearing of muscles followed by the formation of fibrous tissue, extensive hæmorrhages, may each give rise to this condition, but it is more often associated with clumsy splints and over-zeal in an effort to make them effective by tight bandaging.

It is marked by paralysis and contracture of the muscles of the forearm. It usually comes on suddenly, and the contracture is part ot the initial process, and is due to partial coagulation of the proteids of the muscles, caused by lack of oxygen and blood supply. It is therefore a species of coagulation necrosis allied to rigor mortis.

Diagnosis. The position of the hand is characteristic. The metacarpo-phalangeal joints are extended, and the fingers are curled up. If the wrist is passively flexed, the tension of the extensors and relaxation of the flexors cause the fingers to extend without any voluntary effort on the part of the patient. Microscopic examination of the muscles shows a considerable fibrosis—it is therefore a fibrous myositis with which the surgeon has to deal.

The condition is easily distinguishable from one dependent merely on the involvement of nerve. It does not confine itself to any particular nerve-track, but generally affects all equally. Sensation is rarely lost, and muscles supplied by the same nerve may vary considerably in their involvement. The circulation is badly affected, and the nutrition shows serious damage. The finger-nails become black and the fingers mummify. The paralysis is rarely complete.

Treatment. The author has long since discarded operative procedures such as lengthening of tendons or shortening of bones, as he finds that a properly conducted mechanical campaign is far more effective, if the muscles are gradually stretched, joint by joint, beginning at the fingers.

First. An assistant passively flexes the wrist to allow the fingers to extend, and each finger is separately strapped to a little gutter-shaped splint, so that they cannot curl up.

Second. A day or two later, or in milder cases at the same sitting, the metacarpo-phalangeal range is stretched and the palm and splinted fingers are bandaged to a flat metal splint. The whole hand and fingers are now rigidly fixed with the wrist flexed.

Third. The wrist is now from day to day extended a little and fixed. This is continued until the wrist is hyperextended. This hyperextension of wrist and fingers is maintained for some time in obedience to the principles laid down concerning the extension of scars, massage being systematically practised.

The reader will note that by this simple procedure he does much more than any operation would effect. He stretches *all* the scar tissues in the direct order of their tension: those most contracted are attacked first. The muscles most infiltrated with fibrous tissue are really the seat of a diffuse scar, and the effect of continuously stretching them releases the pressure upon the vessels.

As a result the circulation of the fingers is rapidly restored, and quite soon fingers which were originally shrivelled like a bird's feet fill out and develop fatty pulp, the scar tissue becomes pliable and, where the destruction of muscle has not been too extensive, function returns.

CHAPTER VI

JOINTS OF UPPER LIMB

1. **Sterno-clavicular joint:** Ligaments:—

Above—Interclavicular from one clavicle to the other and attached to the top of the sternum between.

Behind and in front—comparatively weak sterno-clavicular ligaments.

Below—The strong rhomboid or costo-clavicular ligament attaching the clavicle to the sternal end of the first rib.

There is a complete meniscus dividing the joint into two synovial cavities.

The security of the joint depends mainly on the ligaments, the shape of the joint surfaces not contributing much.

Movement of the joint occurs only in association with movements of the shoulder and arm.

Rest of the joint. In cases of synovitis or other conditions demanding it, rest can therefore only be obtained by controlling the arm, by bandaging it to the trunk and supporting the elbow by a sling so that the weight of the arm hanging on the outer end of the clavicle shall not drag on to the joint.

Dislocations of the sterno-clavicular joint:

1. Dislocation of clavicle upwards.
2. Dislocation of clavicle forwards.
3. Dislocation backwards.

As the rhomboid ligament is very strong, total dislocation which requires total rupture of this ligament is rare, and most displacements of the sterno-clavicular joint are therefore only partial subluxations, and not complete luxations.

Diagnosis. Complete dislocations are unmistakable, and when recent are easily reduced by ordering the patient to take a deep breath and manipulating the arm over a pad or the surgeon's arm in the axilla, so as to lever the clavicle out and replace the inner end in the notch in the sternum, the difficulty then being to keep it in position. In posterior dislocation the end of the clavicle is said to cause trouble sometimes by pressure on the trachea or the great vessels, especially the innominate artery when it has a 'high bifurcation'. This complication is extremely rare.

Exact diagnoses of the subluxations are not quite so easy, for they may be confused with fractures of the inner end of the clavicle near the joint when contours are obscured by swelling: pain and tenderness in the situation of the joint are essentially a feature. In the case of fracture, there may be upward tilting of the inner fragment, but owing to the wide and strong attachment of the rhomboid ligament there may be a fracture without much displacement. The diagnosis can usually be made by manipulation: in the case of fracture the break may be felt, or it may be localized by finding the point of maximum tenderness to be over the bone, not over the joint. Measurements are of little value in comparing the two sides owing to the difficulty of getting clearly defined points from which to measure.

Treatment. Reduce by manipulating the shoulder.

Fixation consists in a local retention by pad and strapping.

The pad is made of strapping folded six or eight times, sticky side out, big enough to make a flat pad covering the inner end of the clavicle and top of the sternum. By being moulded to the shape of the underlying structures, and by sticking to the skin, a pad of this sort gives a considerable amount of local control. The pad is fixed down by a broad strip of adhesive plaster arranged in bandolier fashion over the shoulder.

The arm and shoulder should be fixed very much as for a fractured clavicle. Strips of plaster can be arranged round the shoulder so as to draw it backwards or forwards as may be required in the individual case. The sling supporting the elbow can be shortened when it is found that by raising the shoulder the inner end of the clavicle is kept in position better.

The surgeon should not allow himself to be tied down to one routine method of adjusting the strapping and bandages, but be prepared to modify these to meet the peculiarities of each case. Unless from local pressure no serious symptoms accompany this lesion. The movements of the scapula are hardly ever affected and I have never had occasion to arthrodese or wire the bone. A temporary metallic fixation might be needed in recurrent displacement in the case of a young woman.

2. **Acromio-clavicular joint.** Ligaments:—

1. Superior, fairly strong.
2. Inferior, strong.
3. Coraco-clavicular.

The front and back of the joint are covered by the attachments of the deltoid and trapezius muscles respectively.

The only common injury is dislocation of the outer end of the clavicle upwards. As the joint surfaces are practically flat there is nothing to retain the bone in position except the ligaments. It is essential, therefore, that after rupture these should unite well and be short and strong. If they do not the patient is left with a shoulder in which the recurrent slip of the joint may give annoyance, perhaps in the middle of some important movement in connexion with his work.

Treatment is very simple, replacement is easy. Retention of the bones in position long enough to ensure strong repair is almost entirely

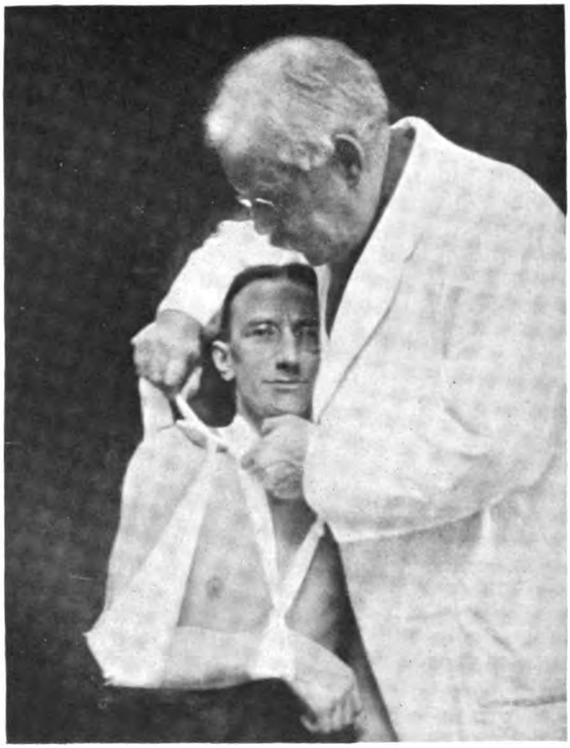

FIG. 291. PUTTING UP ACROMIO-CLAVICULAR DISLOCATION.

neglected by the majority of the profession. Place a firm pad about two and a half inches long by one and a half inches broad over the outer flat part of the clavicle. Put a clove hitch round the wrist and sling the wrist from the neck with the elbow at a right angle. Place a second pad with a hole in the centre of it to lodge the olecranon so as to avoid a pressure sore. Pass a long scarf or a broad bandage under the elbow and knot it over the pad on the shoulder. As the knot is drawn tight, the whole arm, humerus, and scapula, and therefore the acromion process, are drawn up and the clavicle is drawn down (Fig. 291).

The writer very often makes pads used in this way of many folds of sticking-plaster, sticky side out, as these adhere to the skin and do not shift. Such a pad is stiff enough to act as a local splint.

The result of this simple procedure is highly satisfactory.

3. **Shoulder-joint.** Ligaments:—

1. Capsular with the so-called gleno-humeral thickenings in it.
2. Glenoid ligament which slightly deepens the glenoid cavity.
3. Coraco-humeral.

The ligaments are not of much clinical importance, as they are really not of much effect in securing the bones in position. The structures which really secure the joint are the muscles attached round the head of the humerus, whose tendons near their insertion blend with the capsule. The most important are:

1. The subscapularis, which covers the front of the joint and is inserted into the lesser tuberosity and the bone below for half an inch.
2. Supraspinatus, above.
3. Infraspinatus, above and behind.
4. Teres minor, behind.

The last three are inserted in order on to the three facets of the great tuberosity.

Below, the joint is not supported by muscle and the capsule is very lax to permit of free elevation of the arm, and it is through this weak portion of the covering of the joint that the head of the humerus escapes in cases of dislocation.

Good X-ray photographs of every injured shoulder-joint should be obtained without delay, for there is no joint so likely to provide traps for the unwary surgeon, and a patient who cannot raise his arm high enough to let him fasten his collar or brush his hair remembers his surgeon daily, but not with thankfulness.

Text-books do not as a rule pay sufficient regard to the anatomical position of muscles in relation to their mechanical effect when a joint is put out of gear by some lesion in its immediate neighbourhood.

Now at the shoulder the muscles round the scapula, supraspinatus, infraspinatus, teres minor, and subscapularis converge on the head of the humerus; the latissimus dorsi, teres major, and pectoralis major converge on the region of the bicipital groove and ridges.

If there is a fracture about the upper part of the shaft of the humerus the tendency of all these muscles will be to pull the humerus towards the trunk, and if the humerus is left hanging beside the body the lower fragment will be displaced inwards roughly at right angles to the axis of the humerus, and the resulting distortion in the neighbourhood of the joints cannot but interfere seriously with the mobility and function of the joint.

Turning again to the muscles, we find that they have a wide fan-shaped distribution over the back and front of the chest, but all converge in a conical fashion towards the shoulder. The axis of this cone runs outwards and slightly upwards.

In order to neutralize the distorting cross tension of the muscles, the humerus should be pulled out in the line of the axis of this cone; the general pull of the muscles will then be along the axis of the humerus straight on to its articulation with the scapula.

This is not explained in text-books of surgery, and is a departure from the traditions which have descended to us from our forefathers.

In every case of doubt, or where there is a complicated smash about the shoulder, the surgeon knows that if he can get the arm well extended in abduction at rather more than a right angle from the side he has at least got the muscular resistance pretty nearly in line with the axis of the limb, and has disarmed the muscles of their most vicious distorting tendencies. This position and its applications will be referred to in connexion with fractures and fracture dislocations.

The rule can, however, be made: if in difficulty, play for safety by efficient extension in a fully abducted position.

Dislocations of the shoulder. Practically every uncomplicated dislocation of the shoulder occurs by rupture of the inferior part of the capsule. The head of the humerus escapes through the rent, the lower fibres of the subscapularis muscle in front of the joint are often injured at the same time. Dislocation therefore occurs most frequently with the arm abducted when a twist with the muscles attached about the bicipital groove giving a fulcrum, or a blow on the upper end of the humerus, forces the head out below the glenoid. This infraglenoid dislocation is rarely seen by the surgeon, because muscular action or the direction of the violence causes the head of the humerus to slip up either forwards under the coracoid process, or backwards under the spine of the scapula.

Of simple dislocations there are therefore usually two types, the anterior or subcoracoid, and the posterior or subspinous.

Some have been at unnecessary pains to subdivide these still further, according to the amount of tearing of soft parts and the greater or less distance that the head of the humerus has been free to travel.

For our present purpose such subdivisions serve no useful purpose.

Diagnosis. Diagnosis of dislocation of the humerus depends on recognition of the fact that the head of the humerus is not in its normal position in the glenoid cavity under the acromion process of the scapula, and by its discovery in some other situation. Normally the rounded contour of the shoulder is produced by the deltoid muscle lying over the head of the humerus. If the head is not in the glenoid cavity, the contour is flattened immediately below the acromion process, and a finger pressed in under the acromion process fails to meet the immediate resistance of the rounded head of the humerus. In fracture of the neck of the humerus without dislocation the flattening of the contour is a little lower down, but the head is felt in situ *immediately below* the acromion. The only exception is fracture of the neck of the scapula, when the head and glenoid cavity may go adrift together. The second point which completes the diagnosis is that the rounded mass of the head is felt in some other situation.

In simple anterior dislocation without fracture of the neck the position of the arm is characteristic. The head lies in front of the neck of the scapula. The elbow is abducted and cannot be brought to the side, and the mobility of the joint is reduced almost to zero, thereby distinguishing the condition from fracture of the humerus, in which there will be abnormal mobility at the site of fracture, whether the head be dislocated or not.

On examination all movements of the arm are restricted, and in particular the elbow cannot be brought to the side, nor can the hand be put on the other shoulder.

Reduction of anterior dislocation of the shoulder. It was Kocher of Berne who first pointed out that in ordinary dislocations of the shoulder the coraco-humeral ligament is rarely torn and that the spasmodically contracted subscapularis muscle binds the head of the bone down to the ventral aspect of the scapula.

The head is usually lodged near to or actually on the edge of the glenoid.

The method of reduction known by Kocher's name is generally accepted as the best and simplest method of reducing anterior dislocations. It depends on tiring out the subscapularis muscle until it relaxes; when this happens the dislocation in many cases is reduced without any effort.

The method of tiring out the subscapularis muscle is by rotating the arm outwards with the elbow bent till the resistance of the muscle is overcome.

There is no force or violence required; the procedure is not painful, and can be carried out without an anæsthetic. Therefore the patient may sit up in a chair; the surgeon places one hand on the flexure of the patient's elbow, and leans on this to produce slight extension; with the other hand he grasps the patient's forearm near the wrist, and slowly but firmly rotates the arm outwards. There should be no hurry and no attempt to twist the head suddenly into the joint. If dealing with a powerful man it may be several minutes before the muscle ceases to resist. While the arm is being rotated outwards the head of the humerus, if not already resting on the edge of the glenoid cavity, travels visibly outwards till it impinges on it. The relaxation of the muscle is usually sudden, and if the surgeon is keeping a firm downward traction on the limb he feels the head slip downwards a little towards the lower part of the glenoid; at the same time the head of the humerus rolls over the edge of the glenoid, and into its proper place. Simultaneously with the relaxation of the muscle, the resistance to adduction disappears, and the elbow can be brought in towards the front of the chest; the arm may then be rotated inwards, when the hand will without difficulty be placed on the patient's opposite shoulder.

Students and others may sometimes be seen to rotate the arm out and then suddenly attempt to adduct the elbow and rotate the arm inwards, apparently with the idea that by so doing the head of the humerus will be twisted into place, and very often they fail, because they are working on a mistaken idea.

The head rolls outwards over the edge of the glenoid; by keeping up a downward traction—a part of the manœuvre omitted by some surgeons—the head is drawn down nearer the point at which it rolled out. In the majority of instances the head will roll into place so suddenly that the reduction is effected before the surgeon has time to adduct the limb and rotate inwards.

When, however, the head is poised on the brink of the glenoid cavity, a little gentle pressure of the elbow towards the front of the chest will upset it over the edge. If reduction is not effected gently, force will certainly fail; therefore it is bad practice to lose patience and resort to force.

Under an anæsthetic, with the muscles fully relaxed, a very small rotary movement will often effect reduction.

A large proportion of cases of death under anæsthesia have occurred when the anæsthetic was administered for the reduction of a dislocated shoulder. If an anæsthetic is to be administered the patient must be properly prepared for it.

The old method of reduction with the heel in the axilla is practically obsolete in its original form, which was that the surgeon placed his foot (with the boot off) in the axilla and exerted traction on the arm first outwards and then downwards, using his foot as a fulcrum over which he levered the head outwards. The method, though effective, involves too much risk of bruising nerves and vessels in the axilla. It is to be avoided.

Traction first outwards in an abducted position, then more and more upward till the arm is being pulled straight upward, is a manœuvre which is sometimes indicated, and is quite sound practice.

In certain cases Kocher's method may fail the surgeon, and in such instances steady traction of the arm in the abducted position, accompanied by a side-to-side swing, will prove effective. The surgeon places the patient's axilla over his flexed thigh while one assistant pulls the arm and another fixes the scapula. Gentle traction completes the operation.

FIG. 292. REDUCING DISLOCATED SHOULDER.

With appropriate machinery, old dislocations of many weeks' standing can be reduced on this principle (Fig. 292).

For the very rare variety of shoulder dislocation known as luxatio erecta, traction upwards is the direct method of reduction, because in this variety the arm is pointing straight up above the head and fixed in this position by the muscles, while the head is below the glenoid.

Backward dislocation of the shoulder is comparatively rare as the result of accident. The head escapes through the lower and posterior part of the capsule, sometimes tearing the lowest fibres of the teres minor;

the head then lodges somewhere under the acromion process or spine of the scapula, lying in the infraspinous fossa.

Diagnosis. The head is not in the glenoid fossa, but can be seen and felt on the dorsum of the scapula. The arm is usually directed forward and rotated inward with more or less adduction, unless the head is displaced far towards the middle line of the body under the spine of the scapula, when there may be some abduction.

Motion is very definitely limited.

Reduction is effected by traction in the line of the arm with gentle rotatory movements, adduction to clear the head from the posterior margin of the glenoid, and gradual raising of the arm so as to turn the head down to the lower part of the glenoid margin and allow it to return by the way it left.

AFTER-TREATMENT

1. Bandage the arm to the side for two or three days to keep the parts at rest, till blood-clot and effusion are absorbed and repair commences.
2. Next carry the arm in a sling, but do not allow the patient to abduct the arm, although small voluntary movements are permitted.
3. Allow gradual increase of movements and practise rotations for about three weeks.
4. Finally secure full abduction by passive movements and exercise.

The risk of causing a recurrence by early abduction makes it necessary to run the risk of a few adhesions, which may have to be stretched as recovery takes place.

COMPLICATIONS

Fracture of the glenoid. In forward dislocations the capsule is not always torn; the margin of the glenoid may give way, either by separation of part of the glenoid ligament and some stripping of periosteum, or by fracture of the bone at the anterior edge of the glenoid cavity.

Reduction presents no difficulties, but the head slips forward again very easily. It is therefore necessary to keep the head of the humerus well back by supporting the elbow well across the front of the chest and strapping the upper part of the humerus back as in the well-known Sayer's method of fixing a fracture of the clavicle.

Fixation must in this case be maintained longer than in a simple dislocation.

Diagnosis is made by crepitus on manipulation, by the ease with which the head slips forward again after reduction, and if doubt exists reduction should be confirmed by the X-ray photograph.

Fracture of the greater tuberosity may occur in conjunction with a dislocation or as a distinct injury without dislocation. It seems to be produced by avulsion of a wedge-shaped piece of bone by the muscles; *when there is no dislocation* the fragment of bone is drawn slightly upwards and backwards by the action of the muscles attached to it (supra- and infraspinatus and teres minor).

The fragment cannot be brought down to the humerus, so the humerus must be brought up to the fragment by abducting the arm from the side, rotating it outwards and bending the elbow till the hand rests on the back of the neck.

The arm is easily fixed in this position by putting a clove hitch round the wrist and passing the bandage behind the head under the opposite axilla, and by a firm spica bandage over the injured shoulder. If the patient is very restless, fix the limb in this position with a spica bandage of plaster of Paris including the chest and arm.

If the arm is not fixed in this position, the fragment and the callus formed round it will block abduction by impinging on the acromion process, and the patient will not be able to reach his back collar-stud, or, if a woman, her hairpins.

The preservation of the ability to do common daily actions, however trivial, is much more important to the patient than the ability to perform some unusual movement which is hardly ever required. If the position of the fragment is unsatisfactory, a screw will fix it, but the operation will be rarely needed.

Dislocation with fracture of the greater tuberosity is a much more difficult problem. First, because the fragment of bone attached to the external rotator muscles lies under the acromion process and may get into the way of the head when reduction is attempted. Reduction should be performed under an anæsthetic:

1. If after reduction it be possible to retain the arm in an abducted and externally rotated position without reproducing the dislocation, this is the position which will secure the best functional result.

2. If the arm must be treated first by the side in order to let repair of the capsule take place (*i.e.* if the dislocation is allowed to take precedence of the fracture), then it is desirable to abduct the arm fully before the newly formed callus is hard. In this way the lump of bone and new callus forming on the outer side of the upper end of the humerus is pushed against the acromion, and can be to some extent pushed out of the way, clearing a free path for fuller abduction than would otherwise occur.

This involves risk of reproducing the dislocation, and must therefore be done with caution.

3. The question of operation to screw the fragment down into position may be considered.

The technical difficulties in the way of performing such an operation, so effectively that the result will be distinctly better than that obtained by non-operative means, are considerable.

Because:

1. The fragment of bone is often small.
2. It is tucked away under the acromion by the retraction of the muscles inserted into it and cannot be easily pulled down into position.
3. The screws fixing it must be put into cancellous bone, which does not hold very well in any case, and gives very little security when there is muscular tension.

Fracture of the neck of the scapula. Fracture of the neck of the scapula may at first sight be mistaken for a dislocation, because the head of the humerus and glenoid drop together, leaving a vacant space under the acromion. On examination, however, the arm is not fixed in an awkward position as is usual in ordinary dislocations, but is fairly movable. The elbow can be brought to the side and the whole arm lifted into position. Sometimes the irregularity at the seat of fracture can be felt from the axilla. An X-ray photograph is essential.

Treatment is obviously to lift the arm with the attached glenoid into position and keep it there by binding the elbow up to the shoulder exactly as for acromio-clavicular dislocation (Fig. 291).

Absorbent wool is placed in the axilla between the arm and the body to prevent soreness of the skin, and the whole arm is then bandaged to the body to keep it at rest.

Dislocation of the shoulder associated with fracture of the neck of the humerus will be discussed below in the section on 'Fractures of the neck of the humerus'.

Fractures of the neck of the humerus:

It is customary to divide fractures of the neck of the humerus into:

1. Separation of the epiphysis in children.
2. Fracture of the anatomical neck in old people.
3. Fracture of the surgical neck.

It will be of advantage briefly to consider our experience of the after-progress of these cases before discussing methods of treatment. The result of long experience is that the functional result is surprisingly good even in cases which one may say have had no scientific surgical treatment in the first instance. Of cases which may fairly be put in this class the author may claim to have had a large experience amongst sailors alone, without mentioning cases which have had treatment on various lines ashore.

In any case several weeks after injury the only thing to be done is to break down adhesions and start active and passive movements to increase the range of movement of the arm. Ultimately, very good movement is usually obtained, the patient being able to put his hand to the back of his neck. On examining this range of movement more critically it is found that a great deal of it is movement of the scapula, while true movement at the shoulder-joint itself is somewhat limited.

When these results are compared with those obtained after excision of the head of the humerus for disease or ankylosis after septic arthritis, one is forced to admit that there is not much to choose between them.

The conclusion is that if practically untreated cases do so well, it ought to be possible by carefully directed manipulation to get such good functional results that operation should only be resorted to in very exceptional cases, when there is some clear indication that there is a difficulty to be encountered which operation alone will surmount. Such cases are so rare that out of many hundreds of instances of this fracture which have passed through the author's hands he has only performed an open operation in four instances, and two of these were for the relief of intra-axillary pressure.

1. **Separation of the epiphysis** in children can be reduced by traction and manipulation described below; once the ends are brought in apposition there is little tendency to recurrence of displacement, and simple fixation to the side with a moderate wool pad in the axilla completes the treatment.

2. **Fracture of the anatomical neck,** the so-called 'intra-capsular fracture' of a former generation, occurs generally in old people, frequently from a direct blow on the shoulder. The line of fracture is never exactly that of the anatomical neck of the humerus, but usually includes in the upper fragment a portion of the shaft in the inner side and sometimes a piece of the tuberosities.

Diagnosis. The shoulder is bruised, swollen, and painful, but the head of the humerus is in the glenoid cavity.

The fracture is often impacted, in which case crepitus will not be obtained on manipulation. On measurement from the prominent point on the posterior border of the acromion to the external condyle shortening is not more than half an inch.

Treatment. If impacted, never attempt to disimpact. Further, the upper fragment is often attached to the lower fragment only by a strip of periosteum or an extension of a muscular insertion, and in consequence, forcible manipulation is strictly contra-indicated. There is usually little lateral displacement of the fragments. All that remains therefore for the surgeon to do is to make the patient comfortable with a modest pad in the axilla, bind the arm to the side of the body, and wait for union.

Massage of the shoulder, not movement, may be employed from the beginning. After a week repair will have commenced, the muscles round the shoulder will no longer be contracted, nor will they be prone to sudden spasms, and support of the elbow in a sling and a light controlling bandage round the body is all that is necessary.

Three weeks after the injury union should be far enough advanced for the patient to attempt gentle active movements with impunity. Recovery with a satisfactory range of movement should be complete in about six weeks.

3. **Fracture of the surgical neck.** Fracture of the surgical neck occurs below the tuberosities; there is often considerable displacement of the fragments and sometimes serious error of alinement.

Accuracy of alinement is of paramount importance in all treatment of fractures. If the two fragments are allowed to unite at an angle to one another or with a rotational discrepancy, the limb which results will work about as well as a pair of wheels with a twisted axle. If the axle is straight, the wheels will go round true—it does not matter how much the axle may be patched so long as it does not hit any working part. So with a broken bone, if the alinement is correct, the line of action of muscles in relation to joints will make for good function; local projections and irregularities do not matter unless they interfere with nerves or muscles, or in the case of a fracture near a joint form a mechanical block to free movement.

One observes from a clinical and radiographic examination of recent cases exhibiting deformity that the upper fragment is abducted by the muscles attached to the great tuberosity, and rotated outwards.

The upper end of the lower fragment is drawn in towards the trunk by the pectoralis major, teres major, and latissimus dorsi, which are all *internal rotators* as well as adductors. It is further drawn up by the biceps and deltoid against the inner aspect of the upper fragment, so increasing deformity. If the upper fragment will not come into line with the lower, the lower must come into line with the upper.

Treatment. Traction on the arm in the axis of the humerus, gradually abducting and rotating outwards till the arm is at right angles to the body or even straight upward parallel to the side of the head, will disengage the lower fragment from the inner side of the upper fragment. In this position the line of traction of the pectoralis major, latissimus dorsi, and teres major is in the axis of the shaft, so these muscles no longer exert a lateral distorting force.

While an assistant is extending the limb in this way the surgeon with his hands feels when the bones have completely disengaged. He then asks the assistant to relax the tension on the limb, while he tries to guide the ends so that they engage end to end.

If they do engage, they can often be gently pressed together and made to lock sufficiently to allow the arm to be brought down to the side slowly and gently, and with a pad in the axilla the arm is securely fixed to the body, with the elbow bent to an angle of forty-five degrees and the wrist slung from the neck. These movements should be performed with gentleness and judgment to avoid injury to nerves and vessels.

Experience has shown that once this manœuvre is successfully accomplished the ends are not likely to disengage, and all that is necessary is to wait for union and then gradually commence movement.

If the shape of the line of fracture is such that the fragments will not lock properly and therefore disengage when the arm is brought down to the side, the arm must be fixed in the abducted position. In this position the line of traction of the pectorals and latissimus is practically the axis of the limb, and therefore will only pull the two ends towards each other and not laterally, and usually the fragments will not slip.

The whole arm, shoulder and upper limb, is swathed in one layer of cotton-wool. It is best to roll up a whole length of cotton-wool and apply it like a bandage. Over this a plaster bandage is applied to the arm and upper part of the chest, rubbing it firmly in round the shoulder and axilla and again firmly round the bony points about the elbow. A proper grip of the condyles of the humerus prevents shortening of the limb; to make sure of the external rotation the forearm should be included; if the elbow is bent till the hand is behind the head, the position is not in any way uncomfortable, and the success of the functional result is assured.

Two lengths of strong webbing, like horse-girths or something not quite so wide, one round the axilla and fixed on the opposite side of the table, and the other over the top of the shoulder and fixed to the bottom of the table, give an excellent resistance against which to pull. A roller towel or folded sheet will do, but being more bulky is more apt to get in the way of the surgeon's hands when manipulating the shoulder.

Fracture of the neck with dislocation of the head of the humerus. Fracture with dislocation is more often a fracture of the surgical neck than of the anatomical, and is a most formidable condition to treat, as the functional result is often not satisfactory to the patient. The luxation is usually of the anterior type.

Diagnosis. The limpness of the arm, abnormal mobility and crepitus, all point to a diagnosis of fracture; the absence of the head from the glenoid cavity should not be overlooked, therefore an examination of the region immediately under the acromion should never be omitted. An X-ray is indispensable. Of course manipulation of the arm has no effect on the position of the head.

To follow the ancient practice of letting the bones unite *in situ,* and later attempt reduction, is to ensure a very poor result.

There are only two lines of treatment:—

(*a*) Manipulation.
(*b*) Open operation.

(*a*) Manipulation systematically carried out under full anæsthesia is often successful. The patient may be fixed with webbing straps, as described above, and an assistant extends and abducts the arm up to the extreme limit of having the arm parallel to the head. This gets the shaft of the humerus right out of the way, and also pulls the pectoralis major well up out of the way.

Meanwhile the surgeon by direct digital pressure on the displaced head may be able to roll it back into the glenoid cavity, when the rest of the process is exactly the same as described in the previous section on 'Fracture of the surgical neck'.

(*b*) Operation is indicated (1) when manipulative replacement fails; (2) when there is serious pressure on axillary vessels or nerves by the displaced head.

The writer's opinion is that manipulative treatment is so often successful that it should be tried first whenever the state of the limb permits.

The operation. The head being usually somewhere below the coracoid process, the ordinary anterior incision from the tip of the coracoid will usually be chosen.

(*a*) The displaced head should if possible be replaced; McBurney's method is very useful, as it enables the surgeon to control the head without unnecessary handling. It consists of drilling a hole through the shaft of the upper fragment and passing a blunt hook through it, to facilitate manipulation for reduction.

(*b*) In rare instances, where the injury is not quite recent and pressure symptoms exist, removal of the loose head may be the only solution of the difficulty. The resulting false joint is sometimes not very effective, as the muscular attachments which form after excision are not a perfect imitation of the natural condition, and the shape of the end of the bone is seldom moulded by muscular action to form a very efficient joint.

The writer has, however, seen very useful joint results after removal of the head.

Stiff shoulder. After any of the previous accidents, dislocation or some form of fracture, there may be considerable cicatricial contractions about the shoulder-joint preventing freedom of movement. The nature of the stiffness is determined as a rule by the fact that the arm has been kept in a sling hanging by the side with the forearm across the front of the body, and it is in this position that the contracting tissues have become consolidated.

The patient can often raise the arm forward pretty well, but this is done mainly by moving the scapula.

Abduction from the side is very limited, and rotation both outwards and inwards is usually very slight.

The injury being an old one, and an X-ray having demonstrated that there is no active pathological condition about the shoulder, treatment may be commenced.

Treatment is directed with two objects: first to obtain increased mobility at the shoulder-joint, and second to train the patient to move the scapula more freely, and thus increase the mobility of the limb as a whole, even if the actual mobility at the shoulder is lost. The latter method alone can be attempted in the case of bony ankylosis at the shoulder, and the best position of the arm to obtain the most satisfactory result will be discussed later.

Stiffness due to *adhesions* about the shoulder-joint.—The procedure is to break down adhesions under an anæsthetic as described in a previous section (p. 743).

The shoulder should then be massaged and rubbed; as soon as the patient comes out from the anæsthetic—gas should be used for preference—he should be made to perform all movements. As his deltoid is out of training from disuse he cannot lift his arm voluntarily at once, but it is necessary that he should perform the full range of movement. This he can do by getting his hand on the wall and creeping up with his fingers until the elbow, arm, and side are flat against the wall. If the patient will resolutely do this a few times every day he will have a useful arm.

Ankylosis of the shoulder is not such a disabling condition as one would expect, provided it is ankylosed in a convenient position. The reason is that by increased mobility of the scapula, the hand can be got into almost any position commonly required when at table or putting on clothes.

First, the arm should be abducted about sixty degrees or more from the side—movement of the scapula will easily replace this amount of abduction. *Second,* the arm should be rotated out far enough for the hand to be brought to the back of the head when the shoulder is raised. *Third,* the elbow should be a little in front of the mid-axillary line, for convenience in handling a knife or fork at table, playing a piano, &c.

If these three points are attended to during the treatment of an injury of the shoulder in which ankylosis is inevitable, the muscles about the scapula will soon learn to increase their range of movement. To hasten this the patient should assiduously practise all possible movements of the arm.

A patient with an arm ankylosed in this position can perform all ordinary movements so unobtrusively that many people will fail to observe he has any limitation of movement at the shoulder.

INJURIES ABOUT THE ELBOW

Whilst the elbow-joint proper has a pure hinge movement, the radio-ulnar joint, by which supination and pronation of the forearm are accomplished, is closely connected with it, and the two together are essential to full and free use of the hand. Any defect in the muscles, ligaments, or articular surfaces connected with these movements is so annoying to the patient that he declares that they make his joint 'practically useless'. This applies particularly to the numerous varieties of muscle strain which occur round the elbow, each one of which gives no trouble except in a particular movement.

The ligaments about the elbow-joint are:

1. Internal lateral of the elbow-joint.
2. External lateral of the elbow-joint.
3. Anterior capsular of the elbow-joint.
4. Posterior capsular of the elbow-joint.
5. Orbicular of the radio-ulnar joint.

Note that the external lateral and anterior ligaments both send strong bands into the orbicular ligament.

The joint is further supported by the mass of muscular origins and insertions closely investing it. Of these the most important are:

Behind {
1. Triceps tendon, which forms a strap binding the back of the joint when the elbow is flexed.
2. The anconeus lying close to the bone on the outer side of the olecranon.
}

3. Pronator radii teres and the other superficial flexor group from the internal condyle.

4. The superficial extensor group from the *front* of the external condyle.

5. Biceps to the bicipital tuberosity of the radius with which a bursa is connected.

6. The brachialis anticus to the coronoid process of the ulna.

The attachments of any of these muscles may be torn or partially detached by violent movements of the elbow in handling implements of toil or sport—hence such terms as 'tennis elbow' and 'golf elbow'.

MUSCLE STRAINS ABOUT THE ELBOW

Diagnosis is made

(1) by the patient's statement that only certain movements cause pain and sudden disability;

(2) by localizing the tender spot by palpation in the attachment of some muscle;

(3) by the exclusion of bone injury by an X-ray photograph.

Strain of the insertion of the triceps may have to be distinguished from:

1. Bursitis of an adventitious bursa which is superficial to the tendon and should present no difficulty.

2. Fracture of the olecranon—which is often only an avulsion of the tip, in other cases a fracture through to the sigmoid cavity; even then the dense periosteum may prevent displacement, but the seat of fracture can usually be recognized by feeling the crack in the bone. An X-ray decides the point.

3. Chronic strain of the triceps tendon may cause inflammation of the bursa situated between the tendon and capsule of the joint and gives rise to pain on pressure by the finger or on tension of the muscle.

Treatment. Extend elbow, apply a straight splint along the front of the arm with pad over seat of injury and firm pressure to limit effusion.

1. If the injury is a recent one repair will be complete in a few days and movement will not cause pain.

2. In cases in which repeated strain has made the area of insertion tender, a firm pad alone over the seat of injury will suffice; but if acute it will be necessary to apply a splint as well. To stop strain on the triceps from being conveyed to the seat of injury apply a pad of sticking-plaster to the tendon of the triceps just above the olecranon and fix with two firm turns of strapping round the arm.

3. Very chronic conditions with a deeply seated small collection of fluid which is not absorbed may be successfully dealt with by the hot needle (Fig. 293), followed by pad and strapping.

Strain of common extensor or flexor origins. It may be possible at times to localize the injury to one muscle, especially if it is only supination or pronation which causes pain, by carefully testing which muscular action is the cause of pain, by passively putting strain on the various muscles, and by eliciting tenderness on pressure over the origin from the external or internal condyle.

Treatment. If the injury is a recent one, fix the limb with the injured muscle relaxed, and apply pressure so as to hasten absorption and prevent effusion of fluid.

In more chronic cases a pad should be applied by means of a strap round the top of the forearm, just below the flexure of the elbow in this

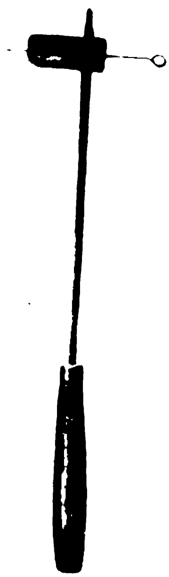

FIG. 293. NEEDLE.

case. To complete the recovery massage and graduated exercise are needed.

Brachialis anticus. Strain of this muscle at its insertion into the base of the coronoid process is easily localized. The muscle must be relaxed by flexing the elbow, while strain is to be relieved by fixing a strap just above the elbow.

Biceps. Strain at its insertion into the bicipital tuberosity on the radius or inflammation in the bursa under the insertion is localized by tenderness on pressure between the upper parts of the radius and ulna, but still more by the fact that passive resistance to flexion and especially supination is painful. Pain on supination distinguishes strain of the biceps from that of the brachialis anticus, for the biceps is a powerful supinator of the forearm as well as a flexor of the elbow, the brachialis anticus being only a flexor of the forearm.

Sprains of ligaments about the elbow are comparatively unimportant as the security of the joint depends much more on muscles than on ligaments. Localization and treatment are fairly obvious.

FRACTURES ABOUT THE ELBOW-JOINT

There is one golden rule regarding fractures of the elbow: they should all be treated with the elbow fully flexed and the forearm supinated, with the single exception of fracture of the olecranon, which requires full extension.

Fracture of the olecranon process.

1. It may be merely an avulsion of a small piece of bone attached to part of the triceps tendon.

2. The fracture may be right across the body of the olecranon process, but the fragment is retained in position by intact periosteum or expansions of the triceps insertion.

Treatment in either of these cases is full extension of the elbow on an anterior splint and a firm pad above the olecranon to stop the triceps from moving it. There being no displacement of fragments in the first instance, none can now occur and union will be complete in three weeks.

3. Fracture across the olecranon with displacement. Here the triceps has already contracted and pulled the fragment out of position, and it is not always easy to obtain perfect apposition and operation may be needed.

Treatment, therefore, is to operate and fix the fragment into position by a screw, a nail or kangaroo tendon, except in the very old or very young. We do not advise operation in the very old, because a reasonably good elbow is obtained by fixing with splint and pad, and the aged are not likely to indulge in very active pursuits. Do not operate in the very young, because screws near epiphyseal cartilages are undesirable; good control can generally be obtained, and an excellent result follows careful treatment with splint and pad.

It is not right to open clean joints at the seat of war, and excellent results can be obtained by fixing the arm in full extension upon a straight splint. The triceps may be rendered sufficiently powerless to allow of adjustment of the olecranon, by placing a pad under pressure over the muscle a couple of inches above the olecranon.

FRACTURES ABOUT THE CONDYLES

The great risk in fractures about the condyles is that the full range of flexion will be lost either by imperfect reduction or by excessive formation of callus, and the knowledge of this risk directs the line of treatment required.

Fracture immediately above the condyles, although *not exactly an injury* of a joint, must be considered as such because if improperly treated the function of the joint is hampered.

The injury usually occurs by a fall on the forearm or elbow. The humerus breaks immediately above the condyles, the elbow-joint with the lower fragment is displaced backwards, leaving the lower end of the upper fragment projecting forward in front of the lower and constituting a mechanical obstruction to the flexion of the joint unless reduction is complete.

The best means of reduction—I would almost venture to say the only means of complete reduction—is a combination of complete flexion of the elbow with downward traction of the forearm. If the limb is then bandaged in complete flexion, with the forearm supinated, *i.e.* the palm towards the shoulder—a good result in every case of simple uncomplicated fracture is practically assured.

The tendon of the triceps muscle arranged like a strap round the back of the joint is a perfect splint. The coronoid process of the ulna tucked into the coronoid fossa steadies the lower fragment in front. No excessive callus can form in front to form an obstruction, because there is no room for it.

After three or four days, when absorption of immediate exudates is well advanced and repair has begun, and when in particular the muscles have come to rest, the elbow need not be so acutely flexed, but the forearm should be slung by the wrist close under the chin.

Between the second and third weeks, when bony union is fairly secure, the wrist may be dropped two or three inches, and the patient may practise active movements daily, producing full flexion and then allowing the arm to fall down to the limit allowed by the sling. If the movement can be satisfactorily performed the sling can be lengthened every two or three days until a right angle is reached, when it can be discarded altogether.

Rule. In any injury or inflammatory condition of the elbow, which has been treated in full flexion with the wrist slung under the chin, the test of recovery is twofold:

(*a*) The absence of tenderness on manipulation about the joint is a sign that the second part of the test may be tried, namely:

(*b*) Lengthen the sling and allow the wrist to drop three inches. If after two days the patient can move the hand from this position back to the neck, all is well, and a daily increase in the range of movement can be arranged.

If, however, the elbow becomes stiff in the new position, it is an indication that the joint or the structures about the joint resent movement—the muscles are on guard, and this indicates that the repair is not far enough advanced to allow movement without damaging the site of repair.

If this happens the elbow should be again put up in the acutely flexed position and an interval of a week allowed before the test is repeated.

A warning must be given against the old right-angled internal splint for the elbow. Satisfactory use of this splint is extremely difficult. Distortions about the elbow are frequently produced by its use, and it is therefore to be regarded as a dangerous device.

First, it provides no easy means of preventing backward displacement of the lower fragment. *Second,* it leaves room for the formation of excessive callus in front of the elbow. *Third,* it is very easy with this splint to press unduly on the internal condyle, tilting the lower fragment outwards and so throwing the joint out of true alinement, and this condition may not be noticed till the patient begins to use his arm—it is therefore an insidious danger.

We may therefore say that the internal right-angled splint for treatment of elbow-joint injuries is to be regarded as absolutely obsolete.

There are cases of compound injury to the elbow, such as bullet-wounds with suppuration, in which it is impossible to treat the elbow in the fully flexed position. A simple form of extension splint for these cases will be described below under ' Compound Injuries '.

Fracture of the condyles involving the joint usually means a fracture running from the trochlear surface to one or both sides, breaking off one or both condyles.

This fracture is produced by falls on the elbow; the sigmoid surface of the humerus acts as a wedge and splits the condyles, breaking off one or both with more or less splintering. This is the most common fracture about the elbow, in adults being commoner than the supracondylar variety.

Diagnosis. The characteristic feature of this fracture is widening of the condyles owing to the split between them. There is also the usual backward displacement of the elbow, and in addition the elbow and olecranon may be displaced to one side or the other. The triceps and olecranon are intact. The X-ray photograph will show the exact nature of the split.

Treatment. Reduction. The surgeon takes the lower end of the humerus in one hand with the thumb above one condyle and the forefinger above the other—the elbow is thus in his hand. With his other hand he pulls the forearm in the line of the limb and gently but resolutely brings the elbow into full flexion with the forearm in full supination. While performing this movement the hand grasping the condyles feels any movement that takes place among the fragments, and by following that movement by gently grasping them they can usually be coaxed into better apposition.

Flexion must be resolute so that any fragment displaced forward is pushed aside out of the way. If any fragment is lodged in front of the joint and blocks full flexion, it should be replaced and fixed by operation should manipulation fail.

The further treatment is exactly that already described, and the most punctilious attention must be given to the rule for testing for recovery before allowing movement. Early passive movement is harmful.

The function that is secured under this line of treatment, by allowing the hand gradually to descend from the fully flexed position till the elbow is at a right angle and then discarding the sling and allowing gravity and movement to restore the tension, is usually excellent.

The range of movement will be from full flexion to some point between a hundred and thirty-five degrees and full extension. Six to eight weeks after the injury, when repair is complete, the last few degrees of extension can usually be restored by forcible movement with or without gas, followed by passive and active exercise.

The elbow often remains permanently broader than the other, which is merely a cosmetic defect, and in the presence of excellent function is not resented.

Operation. The temptation to operate and screw the fragments into position is very great. It is true that this operation successfully performed reduces the broadening of the condyles and therefore leaves a more artistic elbow. Some of the results of operation are absolutely perfect, but the writer's experience is that the average result from the point of view of good functional movement obtained by careful treatment without operation is rather better than that secured by operative methods.

The dangers of operation are increased to an alarming extent if performed where cleanliness cannot be assured.

FRACTURE OF THE CORONOID PROCESS OF THE ULNA

Occurs sometimes in association with backward dislocation of the elbow, and is sometimes produced by muscular violence.

The injury is distinguished from mere muscular strain by the greater disability of the arm, by crepitus on local manipulation, and by the X-ray photograph.

Treatment. All that is necessary is to flex the forearm completely;

this relaxes the brachialis anticus, which is the most important muscle. The tip of the coronoid dips into the coronoid fossa of the humerus, and the parts remain in their normal positions and union will be satisfactory.

It is very rare for the fragment to be displaced so far or to be so engaged in muscles that it cannot be replaced by this means.

FRACTURE OF THE NECK OF THE RADIUS

May occur with or without dislocation of the head of the radius forwards on to the front of the capitellum or external condyle.

Treatment. (*a*) For the simple fracture of the neck the treatment is full flexion of the elbow with the forearm supinated.

(*b*) When the head is dislocated as well as broken off, the displaced head may impede free flexion. The simplest treatment is to remove it. The lump of callus which forms round the broken end of the neck forms an excellent head under the moulding forces of the ordinary movements of the part.

FRACTURE OF HEAD OF RADIUS

Fracture of a portion of the head of the radius is not uncommon. It is very apt to interfere with supination.

Treatment. The rule is to manipulate until supination is easily attained. If failure results then the loose piece can be removed. One of the chief causes of 'clicking' elbow is mal-union of a small portion of the fractured head of the radius.

DISLOCATIONS OF THE ELBOW

Dislocation of the elbow is a much more serious accident than is commonly supposed, because after this injury in the adult, impairment of function often follows, and a frequent cause of this impairment is the condition known as myositis ossificans traumatica.

Myositis ossificans traumatica. This condition, which is frequently associated with dislocation of the elbow, has not received the notice it deserves. Its onset is insidious, and when well established it results in a locking of the elbow-joint, for which no satisfactory treatment has been found.

So far as the mode of its onset can be interpreted, the following may be taken to be a fairly accurate picture.

The original injury results in considerable tearing of muscular attachment from bone accompanied by a large amount of hæmorrhage. With the torn muscular attachments fragments of periosteum and osteogenetic tissue are pulled away, and it is probably these which are the originators of the formation of new bone along the interfibrillary and intermuscular septa. There does not seem to be any way of absolutely preventing detached osteoblastic tissue from forming bone, but we can at least apply our knowledge of the behaviour of cicatrix formations in general, and take care to avoid all that will be likely to provoke the rapidly growing tissues to unnecessary activity.

The usual history is that the patient has suffered from a posterior dislocation of the elbow-joint. The X-ray photograph shows absolutely no fracture or splintering of bone; the outlines of the bones are quite clean and unbroken.

The dislocation is reduced, and after the first effusion has passed away all seems to be going well. Four to six weeks later, however, the patient begins to complain of increasing stiffness, and the practitioner very probably is tempted to resort to passive movement—which is a dangerous procedure.

An X-ray, taken when this stiffness begins, shows a suspicious cloudiness about the attachments of some muscle, usually the brachialis anticus. Two or three weeks later this shadow has become clearly defined, and may even show traces of bone structure. Some years ago we removed the whole of this new bone formation in a considerable number of cases with most unsatisfactory results, because in the majority of instances osteogenesis took place again in the region from which the bony formation had been removed—even when care had been taken to make the operation as complete as possible.

It has already been pointed out that the process of repair in an injured area will be completed with the minimum amount of cicatrix, whether fibrous or osseous, if it is left severely alone in a good position of rest; it has also been laid down as a rule that up to a certain stage of repair movement is injudicious, because it is apt to excite further effusion and increased activity of production of formed tissues, either fibrous or osseous as the case may be.

The systematic use of X-rays has proved that myositis ossificans occurs more or less in a very appreciable proportion of dislocations of the elbow, especially in young subjects.

Treatment. From personal experience the lesson learned has been that every dislocation of the elbow is to be regarded as a serious lesion. After reduction and fixation in full flexion, the limb must be kept at rest till repair has become absolutely complete, just as if the case were one of fracture, and that early passive movement or permission to use the arm freely for all purposes must not be given till the stage at which osteogenetic tissues in or about the site of injury have become completely quiescent and are not likely to be excited to harmful activity.

It is interesting to note that myositis ossificans does not result from fracture of the coronoid process nearly so often as from an apparently simple posterior dislocation.

If the explanation given above is correct, the reason for this must be, first, that the break is a clean one through bone, and not a rough tear of muscle attachments, and therefore osteogenetic cells are not retracted into the muscle to the same extent; and, second, that the fractures having been recognized, most surgeons would naturally keep the limb quiet for a longer period, so that direct union of the bone takes place, the whole process of repair is completed, by which time the period of danger is past.

The sites at which these bony deposits among muscle are most prone to form are:

1. About the insertion of the brachialis anticus.

2. About the biceps.

3. In the lower part of the triceps where the backward displacement tears the shortest fibres of the triceps from their attachment on the back of the humerus just above the olecranon fossa.

Backward dislocations. Backward dislocations may be directly backwards, backwards and outwards, or sometimes backwards and inwards.

1. The head of the radius may go with the ulna.

2. The ulna may pivot on the radius.

3. The orbicular ligament may give way and the head of the radius take a separate course from the ulna, forwards or outwards.

Diagnosis is made by localizing the relative positions of bony points. The particular landmarks are the two condyles of the humerus and the tip of the olecranon, which should be in line when the elbow is extended.

Fixation of the joint is characteristic of dislocation.

Treatment. Reduction is generally easy, first by hyperextension and traction to disengage the coronoid process, then fixation in acute flexion.

After-treatment. Two or three days later, nearly full flexion of the elbow with the wrist slung short up under the chin is required. Complete rest should be continued for three weeks, then movement may be allowed, but not work.

This seems unnecessary, but it is a wise precaution, in view of the possibility of myositis ossificans supervening, and any error in the form of too much movement may provoke excessive bone formation.

Forward and *lateral* dislocations are not so frequent as posterior dislocation. The lateral dislocation may be associated with fracture of one or other condyle.

The reduction of these deformities is usually very easy. If an anæsthetic is given, the slightest movement may cause the bones to slip back into place when the muscles are thus relaxed.

The treatment is the same as for posterior dislocation, but the fear of myositis ossificans is very much less because these displacements, unless very extreme in degree, are associated with less laceration of muscular attachments. The after-progress should be carefully watched, and the slightest sign of increasing stiffness after movement has been free should be taken as an indication for immediate complete rest with the elbow acutely flexed again.

The radius. Dislocations of the head of the radius, apart from dislocations of the ulna, necessarily mean rupture of the orbicular ligament.

The head of the radius is much more closely associated with the radio-ulnar joint than with the elbow-joint, for except in extreme flexion the head of the radius does not articulate with the humerus at all, and in all positions it is in intimate relation to the ulna.

If the orbicular ligament is torn, the movements of supination and pronation may cause the head of the radius to move to and fro instead of pivoting on its own axis.

Therefore, in fixing an arm after reduction of the head of the radius, it is desirable that no to-and-fro movement should occur to disturb the immediate repair of the torn orbicular ligament.

This is most securely obtained, as a rule, by flexing fully in full supination, because then the radius resting on the capitellum cannot slip forward and can generally be easily controlled in every other direction by a pad and bandage.

The question of supination. In all injuries of the elbow, the successful issue of which is doubtful, great care must be taken to preserve supination.

One will remember that in holding a cup or saucer the palms of the fingers must be facing upwards under the saucer; if the radio-ulnar articulation becomes ankylosed or stiff in any other position, the patient cannot hold a tray, plate, or any such object horizontal, and therefore constantly spills things, and this is a daily annoyance which can be avoided by a little forethought on the part of the surgeon.

Ankylosis of the elbow. The common position of ankylosis of which patients complain is with the forearm at an angle of 135° or more to the upper arm. The history usually is that the arm was originally at a right angle and became stiff in that position, but the angle gradually increased afterwards, from which we learn that we must allow for gravity causing an alteration in the angle after stiffness appears to be complete.

The most useful position of the elbow is a compromise. For ease in getting the hand to the mouth, flexion at an angle of 45° is the most convenient, but then there is difficulty, for instance, in reaching over a table for an object lying on it. If, however, the angle is too great, it is impossible to get the hand to the mouth or button a coat. Hence for general purposes an angle just over a right angle is the best compromise, for by bending the head forward the patient can feed himself and yet have a fairly long reach.

Compound and septic wounds of the elbow. Bullet-wounds in the present war, so different from those of the Boer War, have nearly

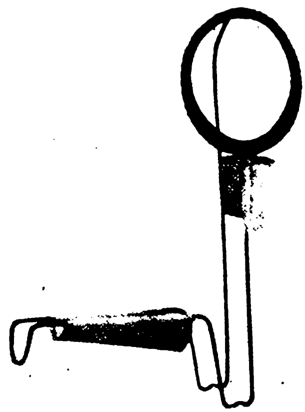

FIG. 294. ELBOW EXTENSION SPLINT.

all been septic, and many have been through and in the immediate neighbourhood of the elbow-joint, especially in the left elbow.

The risks of bony ankylosis would seem to be very great, as frequently the bullet has shattered bone or ploughed through the joint, injuring joint cartilages.

In spite of the havoc of splintered bone and prolonged suppuration, many cases are recovering with a surprising range of movement.

For many months after the inflammatory symptoms have subsided the mobility of the joint can be increased if the general principles already referred to are applied. To attempt to break down adhesions in the traditional manner is to invite failure. By waiting until pain subsides and then gently increasing the range of movement by an alternate 'stretch and rest', the author has been able to obtain excellent function in elbows where an X-ray photograph could offer neither hope nor encouragement. During the suppurating stage a splint should be used which allows of easy access to the wound while the elbow is kept flexed (Figs. 294 and 295).

INJURIES OF THE WRIST-JOINT AND CARPUS

Strains of some of the muscular attachments about the carpus are not uncommon, and the relief afforded by a firm strap round the wrist is well known to the working man.

In addition to these, we have synovitis in the tendon-sheaths, often

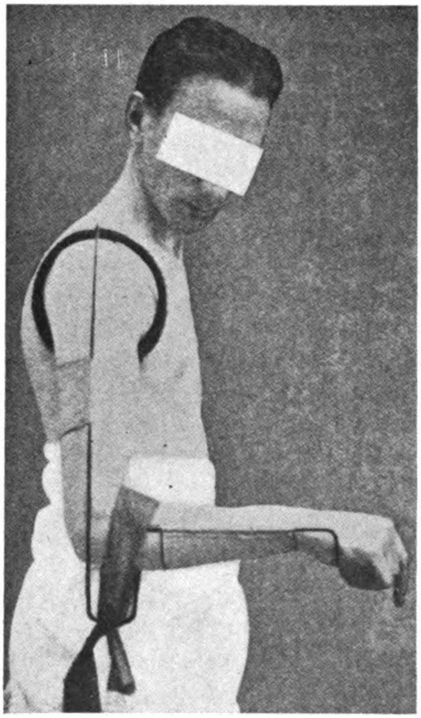

FIG. 295. ELBOW EXTENSION SPLINT. *Applied.*

brought on by a hard spell of some unaccustomed form of work, such as rapid trench-digging or lifting weights.

Bricklayers, for instance, are prone to a synovitis of the sheath of the extensors of the left thumb (ext. ossis metacarpi and ext. primi internodii pollicis). It is almost invariably on the second day of work after a long period of rest that this condition shows itself. It is the repeated full abduction required in picking up and laying bricks that brings on this condition in muscles which are out of training.

For these simple but often disabling conditions the best treatment is a few days' rest, with massage and firm bandaging, followed by gentle exercise. If neglected in the first instance, the slight effusion and considerable tenderness may become chronic, with acute exacerbation, whenever the patient attempts to work.

Sprains of the wrist. If an X-ray photograph is taken of every 'sprained' wrist it will be found that a very large number of them are really cases of fracture of some bone of the carpus, or of a styloid process, and not merely an injury of a ligament.

Fracture of a carpal bone, if the patient is careless and uses the wrist roughly, may result in considerable permanent stiffness.

Rule. Every injury about the wrist below the level of a Colles's fracture may be safely treated with the wrist dorsiflexed (Figs. 289 and 290). Once the wrist has been put into this position, and fixed on the splint shown, the patient may move his fingers after the first effects of the accident are past, without any fear of disturbing repair.

If the lesion results in ankylosis of the wrist, the grasp of the fingers will be good if the hand is dorsiflexed—a fact known to every schoolboy who first flexes the wrist of an opponent when he wants to break his grip. The result of treatment of wrists in any other position is very often stiffness in a position of partial flexion, in which the grasp of the hand is weak. Dorsiflexion of the wrist may in some cases of injury about the joint not be really essential, but it can never be wrong.

Fracture of the carpus. Like sprains of the wrist, fractures of the carpus are usually produced by falls on the hand. The bone most commonly fractured is the scaphoid, and it is usually broken right across its narrow part.

The characteristic point in making a clinical diagnosis is that the maximum tenderness and swelling are found on pressure in the 'anatomist's snuff-box', the name given to the hollow between the tendons of the extensor ossis metacarpi pollicis and extensor secundi internodii pollicis. If this is found, the 'sprain' is usually a fractured scaphoid; the diagnosis may be confirmed by X-ray.

This fracture is easily distinguished from Bennett's fracture of the base of the first metacarpal, as in the latter case maximum tenderness is half to three-quarters of an inch lower down on the ulnar side of the metacarpal, just at the upper end of the first intermetacarpal space. One-half of the scaphoid is often dislocated, usually on to the dorsum.

Treatment. Put the wrist into the dorsiflexed position, or, if this is not possible because a displaced fragment on the dorsum blocks the movement, first try to reduce the displacement by flexing the wrist and pressing the fragment down into its place; if successful, dorsiflexion will be easy.

If this is not successful an attempt should be made to push the displaced fragment out of the way by forcible dorsiflexion. If this method is unsuccessful, no time should be wasted, but an incision should be made over the offending fragment and usually the smaller one removed. By ensuring that the wrist is in complete dorsiflexion before he leaves it, the surgeon will save the patient weeks of trouble and will be sure of a good movable joint in a case which might have ended in a stiff one. The wrist should be kept dorsiflexed for two or three weeks.

In old-standing cases where stiffness has occurred, it is often necessary to administer gas and wrench the wrist into dorsiflexion in order to

FIG. 296. COLLES'S FRACTURE SPLINTS.

improve the value of the hand. The hyperextension splint (Fig. 289) must then be worn continuously for three or four weeks, and at night for some weeks more to prevent contraction during sleep. Operation in the chronic case is only partially successful.

Dislocations of the wrist and carpus. Colles's classical description a century ago of the fracture of the lower end of the radius which goes by his name, definitely put an end to the confusion between this condition and dislocation of the wrist.

In dislocation of the wrist-joint (radio-carpal joint), a comparatively rare injury, the displacement is below the radius, and the styloid process of the radius is in its normal position and relationship to the head and styloid process of the ulna. In Colles's fracture the displacement is half to three-quarters of an inch above the wrist-joint, and even if there is no displacement, tenderness on pressure half an inch above the wrist distinguishes a Colles's fracture from any other. Definite pain on pressure localized at one point in a bone which is either a common site of fracture or in a particular case a suspected site of fracture, is an almost certain proof of one, and should be regarded as such till an X-ray photograph proves that there is no fracture, and then it is certain that the localized tenderness is due to bruising of the periosteum from direct violence, giving rise to a localized inflammatory periostitis.

The dislocation, whether backward, forward, or lateral, is usually easy to reduce. Fixation for purposes of resting the part efficiently is most easily secured in a slightly dorsiflexed position. Massage may be commenced at once; if all pain and tenderness have disappeared after a week, gentle active movements may be allowed. There is usually no necessity for passive movements, and as a matter of experience, disabling adhesions do not commonly occur in a wrist fixed in dorsiflexion.

Fracture of the posterior part of the lower end of the radius, not including the styloid process or anterior border of the articular surface (Barton's fracture), may occur as a complication of a posterior dislocation.

Diagnosis:

1. It is not a Colles's fracture, because the styloid process of the radius is in its normal position with respect to the styloid process of the ulna; and further, on running a finger down the palmar aspect of the radius on to the styloid, the point of tenderness characteristic of a seat of fracture is not found.

2. Such a point of tenderness is found in the dorsum of the radius, probably with crepitus.

Treatment is the same as for Colles's fracture.

Colles's fracture. Colles's fracture, in its typical form, is one in which the radius breaks about three-quarters of an inch from the lower end; the lower fragment being displaced backwards, and usually rotated towards the ulnar side, producing the characteristic dinner-fork deformity. It is produced by a fall upon the outstretched and pronated hand.

The fragments may engage strongly and are sometimes impacted.

The posterior displacement and rotation puts the joint out of true relation to the normal action of muscles; further, the posterior border has several grooves through which tendons run, and when this is displaced backwards it acts as a check on the tendons and is a very material factor in producing functional stiffness of the wrist.

It is therefore desirable that the displacement should be fully reduced, and the normal lines of muscular action restored.

Treatment. Reduction. The traditional method of reduction, by taking a grip of the hand as if shaking hands, still appears in text-books. It is quite inefficient in any stubborn case, for it is mechanically impossible to try to replace a small fragment like the detached lower end of the radius by traction and manipulation through a chain of small bones like the metacarpus and carpus through their ligaments.

The grip the author uses is shown in the figure (Fig. 297). To reduce a left Colles's fracture, the surgeon takes the patient's arm in

FIG. 297. COLLES'S FRACTURE, MANUAL REDUCTION OF DEFORMITY.

his left hand, with his own scaphoid tubercle against the projecting lower end of the shaft; he then places his right hand on the dorsum of the patient's wrist with his own scaphoid on the projecting lower fragment. A firm grip with a slight traction and twist of the wrist completely reduces the deformity. It requires knack rather than strength.

The anterior aspect of the radius has a distinct concavity at its lower end, and the inferior anterior margin projects considerably. If this curve is reproduced reduction is complete.

The fragments can be retained in position by slight pressure of the finger and thumb, one on the upper fragment just above the seat of fracture, and the other on the dorsum of the wrist-joint and styloid process to prevent it from rotating backwards and outwards.

The tendency for the deformity to recur is not great if the reduction is complete, therefore the fracture is put up by replacing a pad of wool on each of these two points, and retaining the pads in place with splints (Fig. 298).

The splints the writer uses are made of thin sheet metal. A slight twist is put on these to make them wrap spirally round the limb, keeping the wrist pronated (Fig. 296).

The *posterior splint* extends from the external condyle of the humerus to about the middle of the metacarpals, and runs spirally from the ulnar side at the elbow to the radial side below.

The *anterior splint* on the palmar aspect of the forearm has the twist in the opposite direction, and must stop short of the thenar eminence.

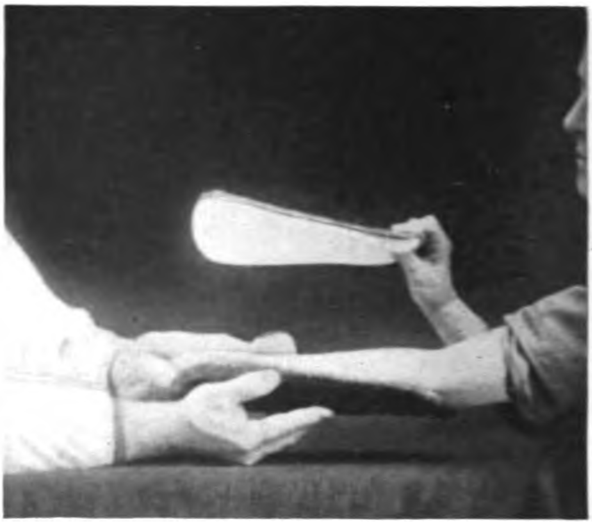

FIG. 298. COLLES'S FRACTURE, APPLICATION OF PADS AND SPLINTS.

A firm band of strapping holds these together at the carpus, keeping the wool pads in place; another at the upper end of the forearm holds the splints on. The spiral twist of the posterior splint is *against* the direction of rotatory deformity (Fig. 299). The fingers are left free: the play of the finger tendons over the seat of the fracture cannot do any harm when reduction has been complete. The forearm is slung at a right angle. A Colles's fracture properly reduced never gives trouble.

After-treatment. No movement which can strain the newly formed callus should be allowed for three or four weeks. It is not uncommon for patients to complain of stiffness and disability for weeks after they have sustained a Colles's fracture. This condition occurs only when reduction has been incomplete.

Mal-union is unfortunately still far too common. The usual faults are imperfect reduction, and strain of the newly formed callus by injudicious passive movement or too strenuous use.

It is true that in a well reduced case the patient can use his wrist at the end of the fortnight, but there is a penalty attached to this, for any rough movement may strain the callus, when the whole wrist will

FIG. 299. COLLES'S FRACTURE PUT UP.

become stiff and painful. If the mistake is made of trying to overcome this by rough movement, the condition will probably get worse instead of better.

The author's practice is to keep the splints on for three weeks, allowing light use of the fingers as soon as the patient likes. After that the anterior splint should be retained, while the patient gradually accustoms the wrist to ordinary work.

Massage is most effective when the fracture has thoroughly united.

Mal-united Colles's fractures of many weeks' standing can be reduced under an anæsthetic by manipulation, or by a Thomas wrench (Figs. 300, 301).

Bennett's stave of the thumb or fracture of the base of the metacarpal is the 'sprained' thumb' of the prize-fighter of former days.

The fracture consists of an oblique split of the base, the corner next the index-finger being broken off.

Diagnosis. It is diagnosed by a complaint of a 'sprained' thumb, which on examination is found to be specially tender just at the angle between the first and second metacarpals, with irregularity of the base of the first metacarpal and perhaps crepitus. The diagnosis is completed by a radiograph. The disability which follows is impaired mobility, especially difficulty in abducting and adducting the thumb.

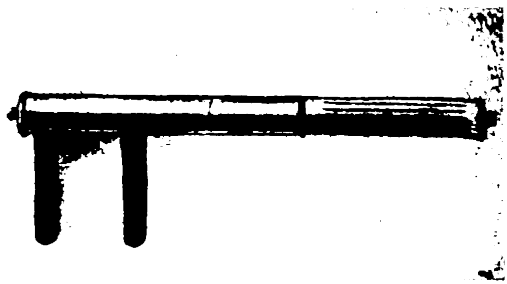

FIG. 300. THOMAS'S WRENCH.

The best position for treatment is with the thumb held in the position occupied when holding a glass of water.

A shoehorn-shaped gutter-splint of thin sheet metal with two strips of strapping, one at the wrist and one at the interphalangeal joint of the thumb, suffices to fix it.

Impacted fracture of the base of the first metacarpal, with the shaft driven straight down into the base, also occurs. It may be firmly bandaged, and left to repair *in situ;* there is distinct shortening of the thumb if this is done. The functional result is satisfactory after a sufficient period of rest to let repair be complete before putting any strain on the thumb.

Dislocation of the first metacarpal at its base is usually displacement of the metacarpal on the carpus outward and backward.

Diagnosis and reduction present no special difficulty, but retention of the bones in position is more difficult unless a suitable splint is used.

A gutter-splint, applied along the dorsum and outer side of the thumb, will meet the case.

Retention should be continued for three weeks, for the action of the flexor muscles tends to lever the base out of position again.

Dislocation of the metacarpo-phalangeal joint of the thumb. The typical dislocation is displacement of the phalanx backwards on the head of the first metacarpal. The injury is caused by hyperextension of the thumb, and is associated with tearing of the anterior part of the capsule. According to the classical description there are two degrees of dislocation. In the first degree the phalanx remains balanced on the dorsum of the head of the metacarpal, the two bones being at a right angle to each other. The second degree is produced by an attempt to reduce by traction where the anterior lip of the

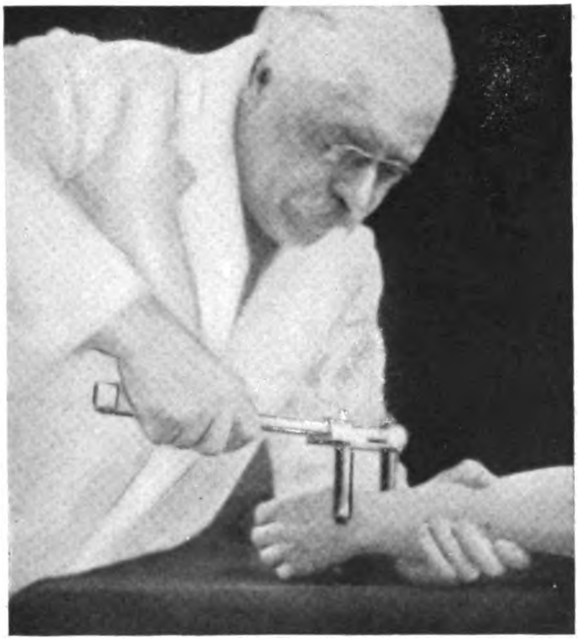

FIG. 301. COLLES'S FRACTURE, THOMAS'S WRENCH APPLIED.

base of the phalanx slips back over the head and the two bones overlap.

Undue prominence has been given in books to the difficulties caused by entanglement of the head of the metacarpal between the flexors of the thumb.

Recent cases can usually be reduced in the first instance. Some unreduced cases can only be reduced by open operation.

Treatment. Reduction is effected by hyper-extending the thumb and pushing and levering the phalanx *base first* over the head of the metacarpal. Traction is absolutely useless.

The joint is placed in the shoehorn-shaped splint already described, and with ordinary care there is little tendency to recurrence.

Old unreduced cases often require operation. The writer uses a lever, which is introduced from the dorsal aspect under the phalanx and over the metacarpal, and in this way the metacarpal head is brought into position.

CHAPTER VII

INJURIES TO THE SPINAL COLUMN

It is impossible to deal fully with the large subject of injuries to the spinal column here. It must suffice to give some general advice on diagnosis and treatment.

The vertebræ articulate in three ways: by their bodies, by their articular processes, and by the ligaments connecting the spines and the transverse processes of adjacent vertebræ, and are further intimately bound together by a very complicated series of spinal muscles.

In making a diagnosis of an injury of the back it is desirable to examine the patient as soon as possible before complications arise to mask the symptoms.

The surgeon must endeavour to apply the principles already laid down for guidance in diagnosing injuries of other less complicated joints.

Setting aside the question of injuries of the spinal cord, graver injuries of the vertebræ correspond to essential injuries of joints, and movement will be restricted in every direction by the guarding action of muscles. It must be remembered that fracture right across the body of a vertebra frequently occurs in the lumbar, and sometimes even in the cervical region, without displacement of the fragments and without compression or injury of the spinal cord. In such cases the absence of paralytic symptoms may lead the surgeon to overlook the gravity of the case.

Such injuries are produced by heavy falls and blows. If the patient is able to sit or stand, which is rarely the case, the weight of the trunk on the injured vertebræ causes a dull aching pain, which becomes acute on any attempt at moving. Examination will show that forward flexion, lateral flexion, and backward flexion are all guarded, the injured region of the back being held rigid by the muscles in every movement.

On the other hand, if the injury is merely bruising or strain of the muscles of the back, the patient will resent forward flexion because it puts tension on injured muscles and ligaments, while if the surgeon places his hand on the back and asks the patient to lean back over it, passively, not actively, he will flex backwards with comparative freedom.

This backward flexion is purely passive. If, however, the patient lies down and is asked to arch his back, he cannot do it without pain, for he is actively using the injured muscles. It is very important to distinguish clearly between flexions which are passive and those which are active.

Similarly, when the injury to muscles or ligaments is unilateral, one side flexion may hurt and not the other, thus enabling an approximate diagnosis to be made.

The position of rest for spinal cases. Should deformity follow an injury of the spinal column, it is always angular flexion (kyphosis) with or without lateral curvature (scoliosis).

The weight of the head and shoulders helps to produce the deformity, and once produced tends to aggravate it. It may be laid down as a rule that a bowed back is mechanically weak.

All grave and doubtful injuries of the spinal column should therefore be put at rest in a slightly dorsiflexed position. A double Thomas frame with a head-piece secures this and gives complete control; the patient can be carried about on it and easily nursed with a minimum of disturbance.

Localization by tenderness. The great groups of muscles of the back lie on either side of the vertebral spines. Therefore, when a muscle is strained or torn, by forcible flexion or by an effort of lifting, or by a direct blow, tenderness will be found to one side or other, not in the middle line. Tenderness on percussion or pressure in the middle line on a vertebral spine is indicative rather of injury to the spinous processes.

Crepitus and mobility and pain near the surface on manipulating a spinous process is a positive sign of a fracture of the spinous process.

In cases of injury of a vertebral body or intervertebral disc, it is rarely possible to obtain definitely localized tenderness by pressure on a spinous process.

The diagnosis of stiff backs, due to adhesions and those due to graver lesions, will be given below. All doubtful cases, cases which for the moment do not allow of accurate diagnosis, and cases associated with injuries of limbs, can be treated on the Thomas frame with head-piece, in the first instance, with perfect safety.

FRACTURES

Cervical vertebræ.

1. Fractures of the spines are rare; the spines are short and deeply embedded in muscles.

2. Fractures of the body and dislocations of the cervical vertebræ are not uncommon, but are so often fatal that cases which come under active treatment are comparatively rare.

The cases which survive are those of partial dislocation and fracture of the body with only a partial slip of one fragment.

(*a*) Dislocation of the atlas forwards on the axis is sometimes not fatal, particularly if it is associated with a fracture of the axis allowing the odontoid process to go forward with the anterior arch of the atlas.

Diagnosis. The chin is depressed on the neck and the spine of the axis is felt as a prominence behind. In the normal neck it is too deeply situated among the muscles to be easily felt. The only cervical spine which can normally be felt is that of the seventh vertebra.

Treatment. An anæsthetic should be given; the surgeon draws the patient's head up over the end of the table, and extends and hyper-extends gently to reduce the displacement. The hyperextension should be maintained after reduction.

Fixation of neck injuries. A most efficient emergency splint can be made out of a newspaper and a triangular bandage.

The whole newspaper should be folded and refolded; its length when folded should be just long enough nearly to encircle the neck.

The middle should be as wide as the distance from the top of the sternum to the chin, with the head held up.

The ends should taper a little to fit under the occiput. This is rolled up in the triangular bandage; when put round the neck the ends of the bandage cross behind and are brought round and tied in front.

The top of the collar supports the jaw and the tips of the mastoid processes, and is a great comfort to the patient in all cases of injury to the cervical spine or its musculature.

(*b*) Partial dislocation and fracture of the body also occurs commonly by a fall from a horse. The third and fourth cervical vertebræ are usually injured.

Sometimes only one side of the upper vertebræ or fragment is displaced forwards.

Diagnosis. The patient holds his head rigidly in a flexed and wry-necked position, but accurate diagnosis cannot be made without the aid of radiography.

Treatment. Reduction should be attempted under an anæsthetic as above, the traction being accompanied by lateral flexion to disengage the displaced side of the vertebræ.

Fixation after reduction. In dislocation and fractures of the bodies of the vertebræ the spinal cord is usually injured against the upper edge of the body of the vertebra below the displacement, therefore flexion of the neck must be studiously avoided, both in manipulation and in after-treatment. When reduction has been effected, the head and neck must be fixed at once in hyperextension. The most efficient means is plaster of Paris fitting close up to the jaw and mastoid processes and including the upper part of the trunk.

It is difficult to say what should be done in the field. To remove a patient with a broken neck may destroy his only chance of recovery. If the muscles are relaxed it would be sound practice to hyperextend and reduce at once, slipping a folded coat under the shoulders and back of the neck. To prevent sudden flexion of the neck in a jolting ambulance, a collar should be improvised to hold the jaw up. The newspaper collar described above should be taken as a pattern, a broad strip of bark, leather cut from a saddle, or any other available material being used for stiffening, and the sides of the head should be steadied on the stretcher with sand-bags.

Dorsal region. The dorsal region of the vertebral column is so well buttressed by the ribs that fracture of the bodies is practically unknown, except in severe crushing injuries, which are usually fatal from rupture of internal organs.

Fractures of the spines of the vertebræ, however, are here comparatively common. They are not important, apart from the rare occurrence of fragments being driven in and pressing on the cord (*vide infra*).

The lumbar region. In the lumbar region, as in the neck, heavy falls with the body curled up are liable to produce fractures of the bodies of the vertebræ. Owing to the interlocking between the articular processes dislocation without fracture is almost impossible; but by reason of the great strength of the anterior and posterior common ligaments, and the strong psoas and erector spinæ muscles supporting the vertebræ, fracture frequently takes place without serious displacement.

Further, as the spinal canal only contains the cauda equina and not spinal cord, it naturally follows that cases of fracture of the vertebral bodies which survive to receive surgical treatment are relatively common.

The injury is often overlooked, for it is often accompanied by other injuries and so the graver spinal lesion escapes immediate notice. If the diagnosis is missed and the patient allowed up at the end of three or four weeks, the continuance and increase of pain in the back with the loss of the natural lumbar lordosis, and the appearance of a slight lumbar kyphosis, should rouse suspicion, and the patient should be immediately put on his back on a Thomas frame well arched to restore the lumbar curve before the fracture is too firmly set.

Duration of treatment. So far as the bone lesion is concerned, cervical fractures, if promptly treated, should be firmly united in a month, and if there is no paralysis there is no reason why the patient should not go about with the head supported.

Mid-dorsal lesions require more time, as they have to bear more body weight, but the spinal support carries the shoulders on the pelvis sufficiently well for the patient to get about fairly early.

In the case of lower dorsal and lumbar regions it is practically impossible to carry the weight of the head and shoulders from the pelvis without letting some strain fall on the seat of fracture, and strain means deformity afterwards. Therefore these cases must be kept recumbent for at least ten weeks before any liberty of movement is allowed them.

Poroplastic supports are unsatisfactory in children, and quite inefficient in adults.

STIFF BACK FOLLOWING INJURIES

In patients who have recovered from the immediate effects of an injury to the back, the diagnosis of the cause and the subsequent treatment adopted depend on being able to differentiate between various lesions. They fall under three types:

1. Stiffness due to adhesions among the muscles of the back, due to cicatrization following tears and strains of muscles.

2. Stiffness, pain, and local deformity due to a fracture of vertebræ which has been overlooked.

3. Stiffness due to an osteo-arthritis of many of the joints of the vertebral column.

1. **Cicatricial adhesions among muscles.** The patient is able to go about, but generally complains that he cannot stoop, or when he has stooped can only get up again with difficulty and some pain.

On examining the back, the spinal column is rigid to forward flexion, but the patient can bend back passively over the surgeon's hand to a much greater extent, while lateral flexion may be fairly free. Some localized points of tenderness may be discovered among the muscles, not in the middle line.

The X-ray photograph should exclude a gross lesion of the vertebræ. The bones will be found clear in outline but rather thin in texture from disuse atrophy.

Treatment. The adhesions should be thoroughly broken down, and the patient exercised afterwards. To break down adhesions in the back the patient should be anæsthetized, the thighs fully flexed on the trunk with the knees extended to stretch the hamstrings and buttock muscles, then the movement should be continued, rolling up the trunk very much as a hedgehog rolls up.

Half-hearted attempts only lead to recurrence; thorough manipulation is followed by most gratifying recovery. Next day the patient is made to touch his toes with his hands, and is exercised and massaged, and the adhesions not allowed to recur.

2. **Fracture of a vertebra** which has been masked by other injuries soon makes itself apparent if the patient is allowed up four or five weeks after the injury. He will definitely complain of increasing pain and stiffness, and the tenderness becomes localized. A section of the spinal column is found to be rigid in every direction, for some two or three vertebræ above and below the point of maximum tenderness. A kyphosis is sometimes found in the suspected region. Treatment is that for fractured vertebræ.

3. **Traumatic spondylitis** is an osteo-arthritis with rarefaction of the bone, due to opening out of the Haversian spaces to allow of increased vascularity, and corresponds to the changes which occur in a contused shoulder-joint when the articular cartilage is injured and must be vascularized before it can be repaired.

Diagnosis. The back is stiff and painful. There is a long slight kyphotic bowing, which is quite different from the sharp angular kyphos of collapse of the body of a vertebra found in tuberculous spondylitis, or the sharp localized kyphos due to fracture. The lesion here is probably a bruising of intervertebral disks and articular cartilages by a heavy fall which has forced the vertebræ against each other. The general tenderness and signs of rarefaction are due to the increased vascularization incidental to repair of fibro-cartilage. Whether this explanation is strictly applicable to any particular case does not matter: it suggests the nature of the histological changes and provides a guide to the line of treatment in this type of stiff back.

The X-ray photograph shows the bone less dense than normal, but the outlines at the edges of the vertebræ and about the articular processes are hazy, not sharply outlined—evidence of the general osteo-arthritis, and is very similar to that which occurs in rheumatoid osteo-arthritis of septic origin, only in this case it is definitely associated with an injury.

Treatment. Rest on a proper spinal support, to allow all repair to be completed before the tender vertebræ are required to carry any weight, is all that is required. The patient next gets up in a spinal support which steadies the spine while it learns to carry weight. The support is next removed for massage, and full recovery may take place if care be taken and hurry avoided.

Paralyses associated with injuries of the spinal column. The spinal cord may suffer injury in connexion with injuries of the spinal column.

1. Hæmorrhages may occur in and about the cord as the result of violent flexions even when there is no fracture or dislocation. If the hæmorrhage is in the cord there may be disturbances of sensations to heat and cold as in syringo-myelia. Hæmorrhages about the cord cause

paralysis by pressure (both motor and sensory, more or less complete); the paralysis tends to pass off as the blood-clot is absorbed. In these as in other partial lesions the later stages of paralysis tend to be spastic in type, due to pyramidal track interference. These can usually be treated by massage and assiduous education in voluntary movement.

2. In fracture of the body, as in dislocations, the upper part tends to slip forward over the lower and the cord is nipped against the posterior and upper border of the vertebra below the displacement.

When partial injury of the cord occurs, motor palsy is generally more marked than sensory, and the result is a spastic paralysis with flexion deformities of the lower limbs, as in spastic paraplegia. The prognosis is not as good as in cases of mere interception by pressure of blood-clot, for some of the nerve tracks may be torn and permanently interrupted.

3. Total severance of the cord means complete immediate motor palsy of the flaccid type with complete sensory paralysis below the lesion and a hyperæsthetic girdle above it. In the cervical region this is fatal; in lower regions it may not immediately endanger life, but there are the usual risks of bladder infection and atony.

There is not space here to go into detail regarding the segmental supply of the body and accurate localization, but merely to indicate broad lines of distinction.

Gunshot injuries. In gunshot injuries the bullet or splinters of the hard bone of the neural arches may lodge in the cord or press against it. The associated palsy helps to localize the offending bullet or fragment of bone. Signs of direct pressure on the cord call for operation to remove the bullet or splinter of bone. Sepsis about the track of a wound with a bullet lodged near the canal, is an indication for operation to remove the bullet and drain and disinfect the wound.

The wound should not be probed merely to find out where the bullet is: it involves a risk of introducing sepsis, and is of much less value than an X-ray photograph.

The use of a probe as a guide when operating is quite a different thing, for then the wound is to be opened up and drained. The bodies of vertebræ are generally perforated by bullets without much splintering; it is the hard bone of the various processes which splinters on injury.

CHAPTER VIII

JOINTS OF THE LOWER LIMB

THE HIP-JOINT

THE integrity of the hip-joint depends on the deep ball-and-socket arrangement of the head of the femur and the acetabulum, and on muscular action more than on ligaments. The only ligament of any importance is the ilio-femoral, the so-called 'Y-shaped ligament of Bigelow'.

The landmarks of the joint are:

1. The head of the femur, which can be felt in the groin with the femoral artery pulsating in front of it, below the middle of Poupart's ligament.
2. The great trochanter.
3. The anterior superior spine of the ilium.
4. The tuberosity of the ischium.

Nélaton's line is drawn from the tuberosity of the ischium to the anterior superior spine. It is most easily demonstrated by fixing an end of a tape on the tuberosity with the finger, then bringing the tape across the outer side of the limb to the anterior superior spine, with a free sweep of the hand. The top of the great trochanter just touches this line in the normal limb.

Another simple method is that suggested by Bryant. It consists of dropping a metal tape from the anterior superior spine to the table upon which the patient rests. The distance from the great trochanter to this vertical line is contrasted with that on the normal side. No matter how experienced the surgeon may be, he should never fail to take precise measurements in all injuries about the hip-joint.

Strains of muscles or bursitis about the insertion of the psoas muscle, or the great trochanter, ought to be diagnosed by the methods of elimination described in the introductory chapter.

If all movements of the joint, including rotation, are limited there is an inflammatory condition present, or some serious lesion. If some movements are free but others limited, the obstruction is probably mechanical or due to injury of some structure outside the joint.

Dislocation of the hip. The head of the femur almost invariably leaves the acetabulum and tears through the capsule at the lower part of the joint in this condition. Rotation of the femur plays a prominent part in twisting the head out of the joint.

The Y-shaped ligament of Bigelow generally remains intact and provides a fulcrum which helps in the process of dislocation, and is utilized in the process of reduction. The dislocation is backward or forward according to the direction of the thrust along the femur at the moment of dislocation. Backward dislocation is much the more common form.

Posterior dislocation. This dislocation seems generally to be produced with the thigh adducted, rotated inwards, and flexed, the patient being in a stooping position. Generally something heavy falls on the patient's back, or he is carrying a heavy object on his shoulder and makes a false step.

With the thigh rotated inwards the head is twisted out of the lower and back part of the joint, and then the thrust in the line of the femur makes it travel round the back of the acetabulum to some posterior position.

Diagnosis.

1. The limb is rotated inwards, and slightly adducted and flexed, so that the foot rests on the dorsum of the other foot.

2. On pressing a finger in the groin the resistance of the rounded head of the femur is absent.

3. The head is felt as an abnormal prominence behind, and moves with the trochanter when the limb is moved.

4. Mobility is markedly lessened.

5. By measurement from anterior superior spine to internal malleolus the limb is shorter than its fellow and the trochanter is above Nélaton's line.

Treatment. Methods of reduction have passed through various stages; the ancient method of reduction by forcible direct traction was displaced by Bigelow's circumduction method, which recognized the value of the Y-shaped ilio-femoral ligament as a fulcrum for levering the head into the acetabulum.

Modern methods eliminate the unnecessary parts of Bigelow's sweeping movement. *Bigelow's method:* The patient is placed on his back, while the surgeon by a sweeping adduction flexion and internal rotatory movement of the thigh makes the head travel down the back of the acetabulum to the point at which it left it. Next by a slight lift and abduction the Y-shaped ligament is tightened and the head levered into position as the thigh is extended. If skilfully done in one continuous movement, it is a very effective manœuvre.

The objections are that the sweeping movement may cause unnecessary injury of soft parts, and if the head is not lifted over the edge of the acetabulum, it may travel forwards into the position of anterior dislocation, doing still more injury to soft parts.

The *modern method* of reduction depends on bringing the head down to the lower and back part of the acetabulum and lifting it over the edge, and consists in gently reversing the mechanism by which the displacement was produced.

While the patient lies on his back,

1. Flex the thigh; this brings the head down near the point of exit.
2. Lift, as if trying to lift the patient; if any obstruction is experienced, rotate inwards and lift again. If still obstructed, rotate outwards and lift.

The dislocation may usually be reduced by this method, but sometimes the surgeon feels that the head comes up to the edge of the acetabulum, but fails to slip over; if so, he should gently extend as well as lift the limb, when the reduction will take place. To do this, it may be necessary to strap the pelvis to the table by a couple of groin straps, or the patient may be laid on the floor while the surgeon places his unbooted foot on the perineum to steady the pelvis while he lifts. After a week in bed the patient should be allowed to go about with a plaster-of-Paris spica bandage round the hip, which includes both pelvis and thigh.

Anterior dislocation. The mechanism is not so distinct, but apparently it generally occurs in abduction; the great trochanter engages on the top of the acetabulum and thus tends to lever the head out through the lower part of the capsule. Outward rotation of the thigh twists the head of the femur forward and sets it travelling round the front of the acetabulum into some anterior position.

Diagnosis. The limb is rotated outwards and usually a little abducted; the head is prominent in the groin and is internal to its proper position, which is behind the artery and below the middle of Poupart's ligament.

Treatment. Reduction: slight flexion and pronounced abduction with traction of the limb bring the head down towards the point of its exit. An assistant now places his hand on the head in the groin and presses it outwards and backwards.

Adduction now makes the assistant's hands a fulcrum and levers the head into position. This manœuvre was suggested by Allis, and is most effective.

The more usual routine is a modification of the circumduction method. It consists of flexing the thigh to a little short of a right angle, and both lifting and rotating it. Flexion brings the head down round the outside of the acetabulum into position near the rent in the capsule. Rotation, sometimes outwards, sometimes inwards, with a little lift will usually guide the head over the edge of the acetabulum.

Rotatory movements are particularly useful in clearing the head of any entanglement in muscles, nerves, or the capsule.

The free circumduction movements of Bigelow sometimes led to the head hooking itself in some band of muscle or even in injuring the sciatic nerve. If the manipulation is rough or prolonged, the danger to the sciatic nerve is a real one, therefore all manipulation must be gentle.

Where the head has travelled far from the acetabulum, gentle traction on the limb is of course first necessary to bring the head down towards the acetabulum before the manipulation is practised.

The very rare injuries such as central luxation, where the head is driven through the acetabulum into the pelvis, or anterior dislocations, where the head travels up over the ilium and pubic ramus into the abdomen are very serious and fortunately very rare injuries, for which no routine manipulation can be described.

Fractures about the neck of the femur. The deformity or mal-union which is likely to occur in all injuries of the bone above the small trochanter is determined to a large extent by the shape of the bone and the direction of traction of muscles crossing the hip-joint.

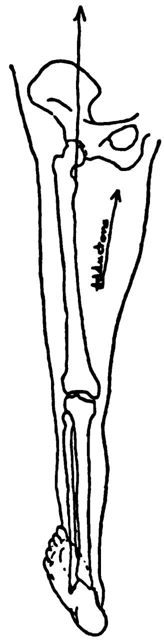

FIG. 302. Diagram showing how in abduction the line of action of the psoas and adductors is normally in the line of the femur.

With the body standing in the erect position the axis of the neck of the femur is inwards, upwards, and forwards, while the shaft sweeps in a curve downwards and slightly inwards to the knee.

In the standing position, with the feet a couple of inches apart, a vertical line from the middle of the head of the femur passes down nearly through the middle of the knee-joint and then through the middle of the ankle-joint.

A glance at the diagram shows that in the case of a lesion about the neck of the femur, the tendency of muscular contraction will be to cause diminution of the natural angle of the neck and shaft (*i.e.* a coxa-varoid deformity), while the adductor muscles tend to adduct the shaft of the femur (Fig. 302).

Experience has shown that the most effective way of disarming this oblique action of the muscles is to apply extension in the abducted position.

The author's experience is that weight and pulley extension is wholly inefficient as a means of fixing fractures, because every time the patient moves his body in bed he alters the tension on the muscles crossing the site of fracture, and this immediately excites a reflex contraction which means disturbance of the fracture and starting pains. The muscles therefore never come to rest. Fixed extension, with counter extension from the tuber ischii of the same or the opposite side as shown in the diagram, permits no contraction of muscles, and they soon become quiescent when this extension is applied (Figs. 303 and 304).

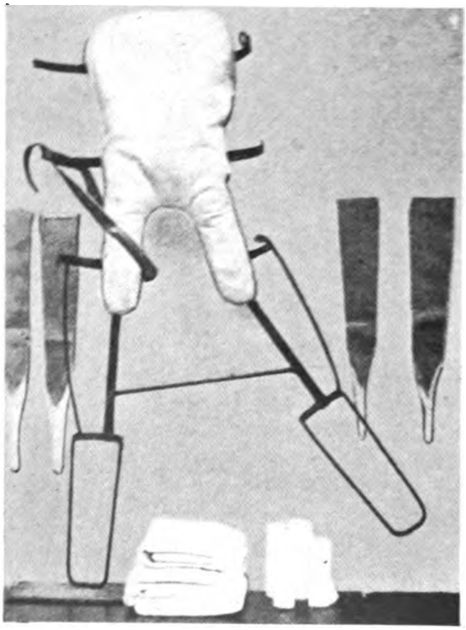

Fig. 303. Abduction Frame.

The common deformity in mal-united or indifferently treated fractures about the neck of the femur, as also in the case of tuberculous or rheumatoid arthritis, is flexion and adduction.

Rule. The lesson is clear that all lesions in this neighbourhood should be treated in an abducted position, the limb being rotated inwards without any flexion. Experience has shown that the results are good. If the surgeon is in doubt or difficulty about a fracture of the acetabulum, he is perfectly safe if he follows this rule.

A partial separation of the head of the femur occurs in young adolescents, and the course of the affection is often insidious. This condition is known as traumatic coxa vara. It consists of a partial or complete separation at the epiphysis of the head, a fracture through the neck, or a fracture involving both neck and epiphysis. It is the most often overlooked of all hip injuries even by extremely good surgeons; it is furthermore often a serious matter for both the patient and surgeon if an early diagnosis be not made. It frequently occurs when turning suddenly; a sharp pain and disability in the hip follows, but the patient is able to walk a little after a rest. The surgeon finds the movements fairly free in the direction of flexion, extension, and adduction; the rotations are distinctly painful, and abduction beyond a short range is not tolerated. The measurements of the limb are normal. Ten days' or a fortnight's enforced idleness, and the patient returns to a normal life. In days or weeks another strain occurs and further disability, with symptoms no more diagnostic than before. After, perhaps, a further strain, the hip becomes painful and the patient lame, and, on examination, the limb has slightly shortened, and a separation of the epiphysis, partial or complete, will be found. The head of the femur is in the acetabulum, but the femoral neck has travelled upwards.

FIG. 304. ABDUCTION FRAME APPLIED.

The injury is much more severe in another type, the disability more pronounced and lasting, and we find we are dealing either with a fracture of the neck, or with a complete separation of the head. There is a third type which completes the clinical group. A youth slightly injures his hip, and is incommoded, hardly disabled, for a day or two. As the weeks pass he complains of an increasing lameness and stiffness at the hip, and his symptoms are very much those of a starting hip affection; there is limitation of movement in all directions, shortening of the limb, elevation of the trochanter above Nélaton's line. A skiagram shows a coxa vara of the epiphyseal type. The slight injury has partly torn the periosteum and separated the epiphysis, and under the strain of body weight the characteristic deformity occurs.

(*a*) The author would suggest that a single strain or a succession of strains of the hip-joint in adolescents, if followed by disability and pain on abduction, denotes an epiphyseal separation.

(*b*) If strain completely disables the patient, and is accompanied by elevation of the trochanter, a fracture of the neck is to be diagnosed.

(*c*) If a slight injury be followed by a limp, rigidity, and shortening of the limb, we are probably dealing with a coxa vara following a partial epiphyseal separation, exhibiting the signs of epiphysitis.

We must remember that a neglected traumatic coxa vara results in a stiff, adducted, and slightly flexed hip. The treatment should consist of immediate fixation under an anæsthetic. With the pelvis fixed while the limb is abducted the upper border of the acetabulum acts as a fulcrum; the limb is secured in extreme abduction and extension by means of plaster of Paris, or preferably an abduction frame, for six weeks until consolidation has occurred.

The sliding head or fractured neck is placed in proper relation with the shaft by this method.

'Extra-capsular' fracture of the neck of the femur occurs typically in active adults up to later middle age. The fracture is usually caused by a blow or fall on the trochanter major. The neck of the femur is driven into the trochanter and may be impacted or may break free.

We should realize that occasionally the patient can walk if the fracture is firmly impacted. The diagnosis can be easily made if the following points are noted:

1. The trochanter major when grasped between the finger and thumb is usually broader than its fellow.
2. Shortening is not great if the fracture is impacted, but may be one and a half inches or more if free.
3. The trochanter is felt to rotate on a shortened radius.
4. Some eversion is usually present.

Treatment. The hip should be well extended in the abducted position. The functional result should be satisfactory, and the shortening not more than three-quarters of an inch.

The old treatment in a long 'Liston' splint is very apt to be associated with some shortening, a good deal of callus which interferes with free movement, and generally some adduction (*i.e.* coxa-varoid deformity) is often found even in cases which have been carefully treated by this method.

If an abduction frame is not available a Thomas knee-splint is better than a Liston, for the ring of the splint gives good counter-extension from the tuber ischii, and the abduction can be arranged by means of sand-bags; but it should only be a temporary measure.

The essential aim in all fractures of the neck of the femur is to secure correct alinement. This is not possible in any position but that of abduction. The limb should be extended, abducted to about forty-five degrees, and rotated inwards. Whitman strongly advocates the use of plaster of Paris to maintain the position, and although the author generally employs his abduction frame, he is convinced of the admirable results to be obtained by fixation in plaster of Paris.

In impacted cases it is advantageous to disimpact in every case where there is considerable shortening or external rotation of the limb, leaving only those cases where the shortening is trivial and where there is no rotation. The results are better than when the old practice was followed of leaving all the impacted cases to unite as they were.

'Intra-capsular' fracture of the neck of the femur occurs typically in elderly people. The fracture is almost always produced by a sudden twist, then the patient falls.

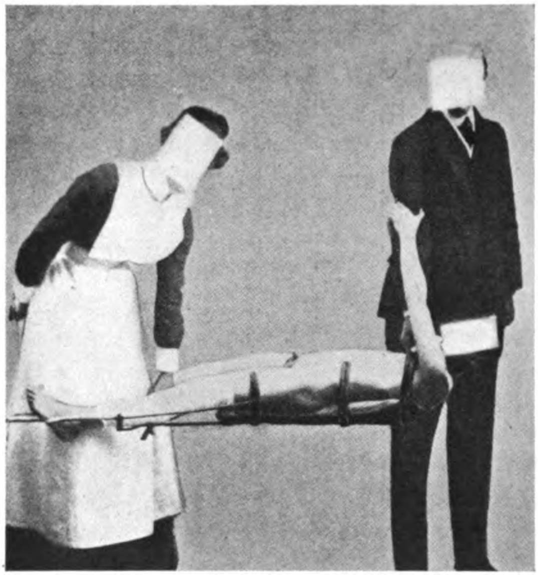

FIG. 305. ABDUCTION FRAME APPLIED: CARRIED.

Diagnosis.

1. Mobility and crepitus between the trochanter major and the head of the femur.

2. Shortening is not as great as in the extra-capsular variety, as the fracture is largely, not entirely, within the capsule.

Broadening of the trochanter does not occur in a typical case.

Treatment. Treatment and its result depends on whether the patient is fit to be kept in bed without risking a 'hypostatic pneumonia'.

If possible, treat in an abduction frame, and a reasonably good result may be expected. If the patient is old and is likely to develop lung trouble if too much restricted, it is better to put on a Thomas knee-splint to prevent shortening, and let the patient sit up.

The case should be treated in the same manner as the so-called 'extra-capsular' fracture. Where hypostatic troubles may be expected, plaster of Paris has advantages over any kind of splint, for the patient need not be confined to his bed. The extension and rotation can be maintained by including the foot in the plaster. In cases where the bone has failed to unite, a well-applied Thomas calliper knee-splint (Fig. 306) enables the patient to walk with comfort. The ring of the splint lying against the tuber ischii supports the body weight.

Plaster of Paris should never be used in compound fractures about the hip. Where suppuration has occurred, it becomes a filthy method. Despite every precaution for the exposure of the wound, the plaster mops up discharges like blotting-paper, becomes horribly offensive, and adds to the infection of the wound.

The patient who lies on an 'abduction frame' can be lifted and moved without pain, without disturbing the fracture or relaxing the extension, and the dressing can be changed without interfering with the mechanism of fixation (Fig. 305). If the wound is through the buttock and the discharge takes place there, the splint can be suitably modified. The abduction frame can be applied in a few minutes.

FIG. 306. CALLIPER.

THE KNEE-JOINT

The integrity of the knee-joint depends entirely on its ligaments and muscles, and consequently it is the seat of many derangements caused by injuries to these structures. The joint is further complicated by the semilunar cartilages and by abundant fatty synovial fringes.

Strains of muscular attachments about the knee may occur at the insertions of the semi-membranosus, at the inner side and back of the internal tuberosity of the biceps, at the head of the fibula, which may be diagnosed by local tenderness on pressure and pain on resistance to voluntary flexion.

Strain of the attachment of the ligamentum patellæ is more important. The tubercle of the tibia is sometimes developed as a separate epiphysis, and the local inflammation then may be of the nature of epiphysitis. Commonly, however, it is a local periostitis which is kept active by the continued action of the quadriceps extensor cruris.

Treatment. If the inflammatory condition is at all severe, a back-splint should be applied to prevent flexion and strain on the painful attachment. In less severe cases a firm band of sticking-plaster applied around the thigh above the patella may suffice to relieve the part sufficiently to allow recovery to take place.

Sprains and rupture of ligaments.

The external lateral ligament is not often sprained and does not often give trouble unless the injury is severe.

The internal lateral ligament, on the other hand, is very frequently sprained. The force which puts strain on this ligament is eversion of the foot and abduction of the leg in slight flexion. One is apt to think of this ligament as a long strap attached above to the internal condyle of the femur and below to the inner aspect of the shaft of the tibia, and to forget that the deep fibres have a very short course from the condyle to the adjacent part of the inner tuberosity of the tibia, and are intimately connected with the capsule. It is these deep fibres which are usually injured in a 'sprained knee', and the injury is most commonly at their attachment to the margin of the tibia.

Diagnosis.

1. The patient complains of pain at the inner side of the knee, particularly when he twists his foot outwards.
2. Pain is caused by passively stretching the internal lateral ligament.
3. There is tenderness on pressure confined to the line of the ligament, not over the anterior end of the cartilage which lies nearer the front of the knee.
4. There is no history of locking of the knee, or of something slipping inside the knee, which would suggest an injured cartilage.

Treatment.

1. Apply a splint until union is complete; this usually takes a fortnight.
2. The patient should deviate body weight from the ligament by walking with his toe turned in.
3. Strain is relieved by making the inner side of the heel of the boot a quarter of an inch thicker than the outer.

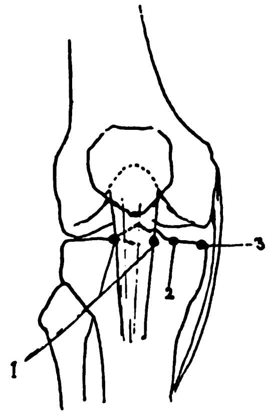

FIG. 307. DIAGNOSTIC POINTS OF TENDERNESS ABOUT KNEE. 1. Tenderness on full passive extension with swelling each side of the ligamentum patellæ suggests a tender post-patellar pad. 2. Tenderness on pressure suggests injury to anterior portion of internal semilunar. 3. Usual point of tenderness in sprain of internal lateral ligament.

Internal derangements. The post-patellar pad of fat is frequently bruised; this injury is often not clearly understood, and is frequently diagnosed as 'rheumatic'. The material fact is that the pad of fat which fills up the space in front of the knee behind the patellar ligament is a little too large owing to hyperæmia, possibly due to a slight bruise.

Diagnosis.

1. Patient complains of pain in the front of the knee.
2. There is a slight fulness at the sides of the ligamentum patellæ which on palpation is not fluid but elastic, being congested fat.
3. Flexion of the knee is painless.

4. Passive extension causes pain, definitely located in the front of the knee behind the ligament.

5. There are often recurrent effusions into the joint.

In cases of long duration which may have been diagnosed as 'rheumatic' or 'arthritis' the thickened pad may cast a faint blurred shadow in an X-ray photograph in a lateral view, due to excess of fibrous tissue. A knee-cage limiting full extension may have to be worn for many months before the thickened tissue all disappears.

Treatment. Prevent repeated pinching of the fatty pad by making the patient wear a jointed knee-cage which allows full flexion but stops twenty-five to thirty degrees short of full extension. This allows the congestion of the pad to disappear without laying up the patient, and then the knee can be extended without causing pain.

Injuries of semilunar cartilages.

The internal cartilage on account of its shape and attachment is more frequently injured than the external.

The mechanism of the injury is nearly always the same. The foot is fixed in eversion. The body suddenly swings inwards with the knee bent inwards.

(*a*) *First,* the internal lateral ligament usually gives way.

(*b*) *Second,* the knee-joint opens on its inner side and the semilunar cartilage, which is strongly attached to the ligament, is pulled out of its place; it may merely bend or one of its end attachments may give way, most often the anterior end.

(*c*) *Third,* as soon as the patient falls and the strain on the knee is relieved, the joint shuts with a snap and pinches the cartilage.

1. The cartilage may be merely bruised and slip back into its place.

2. In the typical case it is split or broken, or the end is doubled over and nipped so that some part of the cartilage fails to get back to its proper place.

When this happens we have the characteristic symptom of 'locking', *i.e.* owing to the obstruction nipped between the bones the leg cannot be fully extended at the knee.

Diagnosis is made

1. By 'locking' when present, or the history of the knee having been locked.

2. By tenderness over the injured internal lateral ligament.

3. Tenderness on the upper edge of the tibia half an inch to the inner side of the patellar ligament.

Treatment. Complete reduction of the displaced portion of cartilage is essential. The surgeon should not be content till he has the knee *fully* extended. Mere partial reduction means constant bruising of the nipped portion, with symptoms similar to those of a bruised post-patellar pad, only the pain is situated more to the inner side of the joint, and is usually more acute.

Reduction. With the patient lying on the back, flex the thigh on the trunk, flex the leg on the thigh, rotate outwards and abduct the leg to open the inner side of the knee-joint and clear the cartilage. Then very rapidly rotate inwards and extend. The cartilage will often slip in during the inward rotation.

If reduction is complete, the knee is fully extended with ease, and the patient feels the cartilage is 'in'. If the patient does not know that the cartilage is 'in' the reduction is not complete.

When working without an anæsthetic the author asks the patient to kick his leg into full extension, counting one, two, three, *kick!* On the word 'kick' the patient violently extends thigh and leg, while at the same instant the surgeon rotates inwards and helps the extension by pulling on the foot. With a little practice this manœuvre seldom fails.

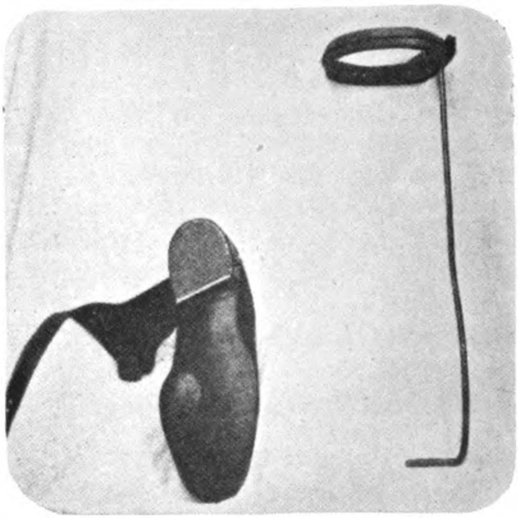

FIG. 308. BOOT AND IRON.

Cases that have remained incompletely reduced for any length of time generally require an anæsthetic. Often when the surgeon has failed to reduce the displacement, the patient suddenly makes some unconscious movement, relaxes his muscles, and reduction occurs spontaneously, which proves that reduction is not a matter of force, but rather of knack.

After-treatment. There is always a good deal of effusion in and about the joint. When full reduction has been attained, the knee should be firmly bandaged on a back-splint for a few days till all effusion has disappeared.

The patient may then walk about with the posterior splint on, to let repair of torn structures take place. If the torn or displaced portion of cartilage gets fixed down, no further trouble may occur.

Then a pad may be placed on the inner side of the knee, and the joint firmly bandaged or strapped and the patient allowed to walk under certain restrictions.

He must carefully avoid everting his foot for fear of stretching the internal lateral ligament and allowing the cartilage to slip again. To enforce this position, the inner side of the heel should be made a third of an inch higher than the outer side; this makes the patient turn his toe in, and by throwing his weight on the outer side of the foot tends to give him a bow-knee rather than a knock-knee, so keeping the inner side of his knee shut (Fig. 308).

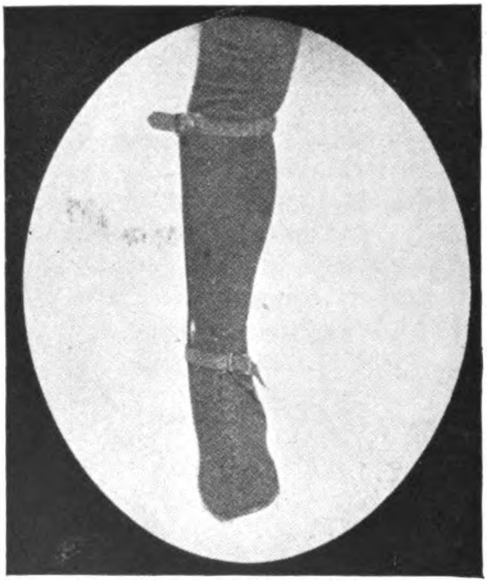

Fig. 308a. Boot and Iron applied.

The external semilunar cartilage. Injuries of the external semilunar cartilage are rarer. The signs and symptoms are less distinct, and the mechanism is not so obvious.

The patient complains of something slipping in the knee and may state definitely that the sensation is in the outer side of the joint. Pain is usually referred to the outer and posterior sides of the joint, pain on pressure is not pronounced, effusion is not so common, and a loose external cartilage often gives rise to the 'clicking' knee.

The indications for operation. Recurrent derangements demand operation, more especially those cases often accompanied by acute symptoms. Where a strenuous athletic life is a means of livelihood, a physical necessity, or where the subject works in dangerous places, there should be no hesitation in urging an operation. No soldier, the subject of a slipping cartilage, should be passed for service until the defect has been put right. Already many have returned from the front because of this disability.

A first attack efficiently treated may result in a cure without recurrence in a large number of cases; therefore, unless there are special reasons, operation is not to be urged where the knee has only once given way.

THE OPERATION FOR EXPOSING THE INTERNAL SEMILUNAR CARTILAGE

Incision. The J-shaped incision frequently employed is open to objection, for by carrying the lower end of the incision backwards, it is easy to cut part of the internal lateral ligament, with lasting impairment of its efficiency.

The incision the writer employs is made as follows: The patient's leg is allowed to hang over the end of the table with the knee bent at a right angle. The incision, about one and a half to two inches long, crosses the joint over the anterior end of the cartilage, following the margin of the articular surface of the condyle of the femur.

The knife used for the skin incision should not be used for opening the joint, for fear of infecting with staphylococcus albus from the skin, if with no more virulent organism. In the flexed position an excellent view is obtained, the internal lateral ligament is well back out of danger, and there is really no excuse for encroaching on it. The offending object, cartilage or fringe, should be cut clean away with a thin-bladed knife without dragging on it. If a tourniquet is first applied, there is no bleeding to obscure the view. The tourniquet should not be removed until the operation is ended and the knee bandaged.

The surgeon who operates upon a healthy knee-joint should be clean beyond reproach. He should have an antiseptic conscience. His finger should never enter the wound however scrubbed or thickly gloved, as an infection would prove a tragedy.

The synovial membrane and capsule should be carefully sutured with a reliable catgut handled and tied by forceps, and the skin then separately stitched so that there is no immediate connexion between the skin wound and the joint.

The after-treatment is the same as for a successfully reduced cartilage. The patient may walk in a back-splint ten days after the operation. A week later he may be promoted to a firm bandage and a crooked heel, and begin to bend the knee. In six weeks he may play games and do what he likes.

Dislocation of the knee. Fortunately dislocation of the knee is very rare; the nature of the displacement is too obvious for any error in diagnosis to take place.

The interesting fact is that in spite of the extensive rupture of ligaments, including the crucial ligaments, the functional results in recorded cases have been so good. The explanation of this is that the lesion is so formidable that prolonged fixation is absolutely necessary; early use and movement is impossible without displacement occurring. Hence torn structures are usually given time to unite firmly, and with exercise and use, considerable freedom of movement is recovered in time. No surgeon sees many cases in a lifetime, so that it is necessary to deduce clinical lessons from recorded cases.

The great lesson seems to be that if the displacement is reduced and the limb fixed in a straight position, nature will do surprisingly well.

Rupture of the crucial ligaments and fracture of the spine of the tibia. These accidents occur as the result of forcible twisting of the knee without sufficient displacement occurring for the case to be diagnosed as a dislocation of the knee.

The pain and effusion at the time is so great that the practitioner necessarily does the correct thing by fixing the limb on a posterior splint.

Patients are generally seen by the consulting surgeon at a later time and complain of preternatural mobility and insecurity in the knee.

The **diagnosis** of rupture of the crucials is not difficult if we remember their anatomical functions.

1. The anterior crucial ligament is tense when the knee is fully extended and prevents the tibia from being displaced forwards on the femur.

2. The posterior crucial ligament is tense in complete flexion and prevents the tibia from being displaced backwards on the femur.

3. Both ligaments check inward rotation of the tibia.

Hence, when it is found that after an injury to the knee the tibia can be displaced backwards or forwards, or rotated inwards in the extended position, an injury of one or both crucial ligaments may be diagnosed.

When in the extended position the tibia cannot be displaced forwards, it may be assumed that the anterior crucial is not torn across.

If in full flexion the tibia cannot be displaced backwards, the post-crucial is not ruptured.

Treatment. Fixation of the knee in the straight position to allow the stretched structures to shorten, followed by the use of a knee-cage to steady the knee when walking, will generally lead to a satisfactory result.

Operation in the author's experience does not achieve much. The torn tissues may be drawn together with sutures, but the ends cannot be accurately approximated with the knee bent so as to expose the inter-condylar space. With the knee-joint closed it is not possible to get in to tie the knot. The good results therefore must be more due to the after-treatment, which allows of sufficient rest to permit the repair tissue to consolidate and shorten.

Fractures of the spine of the tibia. Passing next to fractures of the spine of the tibia, the injury is generally associated with rupture of one or both crucial ligaments. The fracture is probably produced by a combined slide and twist of the condyles on the tibia so that the intercondylar margin sheers off the spine.

Diagnosis between ruptured crucial ligaments and fractured spine is easily made by the X-ray photograph.

Treatment. It is essential to get the knee straight; if there is bone lodged in the front part of the joint it must be got out of the way.

Manipulation of the knee and forcible extension may succeed in driving the obstruction up between the condyles, where it will be out of the way and can do no great harm. The knee can then be fixed on a back-splint and left to recover. There will be some limitation of flexion in many cases, but as a rule the functional result is gratifying.

When the obstructing fragment cannot be dislodged by manipulation, there is no choice left but to operate.

Operation. The incision is determined to some extent by the location of the fragment. It may be possible to remove it by an incision to

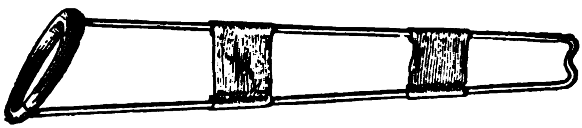

FIG. 309. THOMAS'S KNEE-SPLINT.

the side of the patellar ligament, but in order to obtain a ready access and a good view, the patellar should be split vertically as well as the quadriceps and patellar ligament. After the joint is explored the ligamentum patellæ, the quadriceps, and the aponeurosis are stitched. No wiring or plating is needed.

Fractures about the knee-joint. All fractures about the knee-joint can be fixed efficiently on a Thomas knee-splint (Fig. 309), and the patient can be moved in this splint with less discomfort than in any other known to the writer.

Fracture of the femur above the condyles. The traditional method of treating this fracture is with the knee flexed, because the gastrocnemius muscle is expected to tilt the short lower fragment backwards, and by this means pressure would be put on the popliteal vessels, endangering the vitality of the leg and foot. This fear is entirely without foundation, provided the limb is so securely fixed that reflex muscle-spasm is not excited.

Reflex muscle-spasms and the resulting starting-pains are excited by alterations in tension of the muscles crossing the site of fracture, and can only occur if it is possible for the muscle to contract.

If extension straps of adhesive plaster are applied in the usual way, and firmly fixed to the bottom of the splint, and the ring is firmly up on the perineum and tuber ischii, it is mechanically impossible for the muscle to shorten. The consequence is that no reflex action occurs, and all the muscles of the part become relaxed and restful within twenty-four hours.

The extension plasters should be of strong linen-backed sticking-plaster—one on each side of the leg, with stout webbing stitched on to the lower ends.

They are applied to the limb in the usual way, taking as high a grip as the wounds may permit. The malleoli are protected from pressure.

When fastening the lower end, one band is taken over the side-bar, the other under, and the two knotted over the U-shaped bend at the

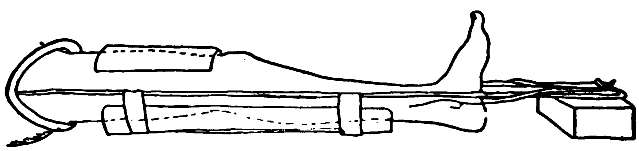

FIG. 310. DIAGRAM SHOWING THOMAS'S KNEE-SPLINT AS USED FOR FRACTURE OF THE FEMUR BELOW THE SMALL TROCHANTER, ABOUT THE KNEE AND UPPER PART OF THE LEG. Arthritis of knee, compound fracture of patella, &c. The gutter-splint behind is slung from the side-bars.

If necessary to get free access to a wound about the knee, leg and thigh would be separately slung. To avoid confusion, only the lower end of the extension plaster is shown; also all bandages and padding are omitted.

The anterior splint is such as would be used for fracture of the shaft of the femur. The block supporting the end of the splint keeps the heel off the bed and protects the heel.

bottom of the splint, which is purposely made to prevent the knot from slipping off (Fig. 310).

The limb is slung from the side-bars as shown in the diagram, or the method modified to leave access to wounds which have to be dressed.

Fractures of the condyles. One or both condyles may be knocked off. The tibia then has a tendency to slip to one side or other.

It is very rarely necessary to resort to operative interference.

Extension strapping is applied up to the knee, the Thomas splint is slipped over the limb, and an assistant applies extension; if he puts his knee against the end of the splint, he gets his own counter-extension from the perineum.

The surgeon grasps the condyles between his two palms, and generally will get the broken fragments to slip together. A firm bandage or, if there is no wound, a few turns of sticking-plaster will hold them together. So long as the tibia is not allowed to bump up against them, they will not be again displaced, and the limb can be fixed as shown in the diagram (Fig. 310).

If the fragments do not slip into place, apply firm extension for a few hours, and try again; the muscles may have relaxed by that time. Often when left alone overnight a displaced fragment is found to have slipped into place by morning.

If in any difficulty an anæsthetic should be given, but this is by no means a routine necessity. Last of all, operation should follow failure of manipulation.

Setting a limb in this way without an anæsthetic does not hurt the patient any more than the usual preliminaries to an anæsthetic.

Fractures of the tuberosities of the tibia are dealt with in precisely the same way. Once the limb is extended and the fragments have been coaxed into position and bandaged there is no tendency to displacement.

One of the great advantages of the Thomas knee-splint in all these cases is that splint and limb are all in one piece, and no movement of the patient's body or other limb can have any material effect on the seat of fracture.

The foot, of course, is fixed at right angles with a figure-of-eight bandage in the usual way.

FRACTURES OF THE PATELLA

Recent investigations have shown that fractures of the patella are much more often due to direct violence than formerly believed. Amongst those undoubtedly due to falls or blows, we must include nearly all fractures of the oblique, stellate, and longitudinal varieties. A very large proportion of the transverse type are the result of a combination of a muscular contraction and of indirect violence. The middle portion of the patella remains in contact with the femur, and this may be snapped by a strain exercised by the quadriceps.

Prognosis. Bony union nearly always occurs in the longitudinal, oblique, and stellate varieties, but only occasionally in the transverse. Excellent function may follow recovery with wide separation of fragments, and not infrequently excellent union may be accompanied by faulty function. The tearing and faulty union of the aponeurosis is a common cause of atrophy and weakness of the quadriceps. The author has seen several cases where secondary fracture has occurred in the original site many months after operative treatment, and it is common experience that if fracture occurs after a good fibrous union, it is not often in the same place.

Treatment. The non-operative treatment must always be employed unless an operation can be performed with the most rigid aseptic precautions, and this should only be undertaken by scrupulously clean surgeons. The introduction of fingers into the wound and the rough handling of fragments play havoc with the patient's chances.

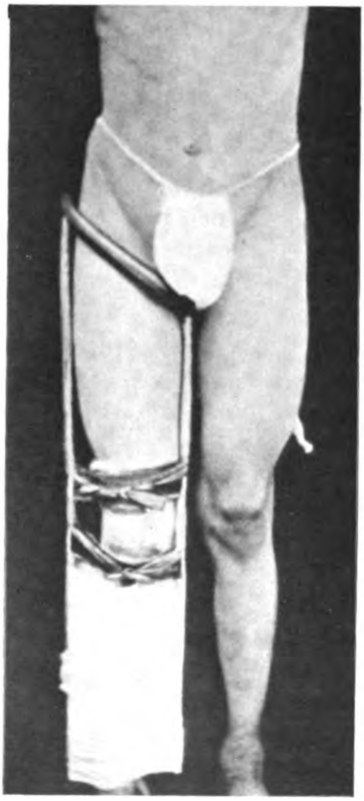

FIG. 311. THOMAS'S KNEE-SPLINT APPLIED FOR FRACTURED PATELLA.

The calliper splint can be applied at once in simple fractures, and as soon as the effusion has gone the patient may be allowed to walk; this generally happens about the end of the first week. The splint is admirably adapted for fixing the upper and lower fragments without circular compression (Fig. 311). The fragments are approximated with the fingers, and a loop of bandage slung round the bars and arranged so as to press upon the quadriceps just above the patella, while another loop is fixed below the lower fragment. Any tilting can then quite easily be remedied by a pressure pad over the riding end. The calliper should remain on for two months, when a small stop-cage brace can be applied, first allowing twenty-five degrees of flexion, and this is gradually increased. The use of the cage gives the quadriceps time to recover without stretching the bond of union, a very important clinical point if the loss of function is largely due to a lax and lengthened quadriceps. While the effusion is being absorbed the limb should be elevated; in this way the quadriceps is kept relaxed.

The author would recommend an operation in all young folk, provided asepsis is guaranteed, but the types of operation suitable to varieties of fractures cannot be discussed in this short book.

Compound fractures of the patella as they occur at the seat of war should not be treated by operation.

CHAPTER IX

THE ANKLE-JOINT AND JOINTS OF THE TARSUS

In fractures of the ankle-joint we must remember, whether the joint be stiff or not, that the patient will want to walk on his foot, and that he should be able to get both the heel and sole to the ground, and a dropped foot or equinus deformity must be prevented.

Whatever the injury, the surgeon must keep the *foot at right angles to the leg;* if he fails in this he has failed in his treatment orthopædically, no matter how skilful or scientific his treatment of the actual lesion may have been.

Strain of the tendo Achillis and sometimes inflammation of the bursa under the tendon are not rare. The condition is really very disabling, especially to men on the march.

A simple device to relieve strain consists in raising the heel of the boot on the affected side half an inch. The patient thus unconsciously does more work with the other leg and avoids strain of the tender tendon. It is obviously of no use to raise both heels, for then the work thrown on both feet would be equal, and the desired effect would not be produced.

It is really practising a species of deception on the patient's sense of balance, but it is very effective in many cases.

Sprains of ligaments. Reference has already been made in the introductory chapter to the means of localizing an injury of a ligament about the ankle and to the appropriate means of keeping down effusion by pressure, and of relieving strain by tilting the heel of the boot, and it is not necessary to refer to them again.

Dislocations of the ankle-joint. Dislocation of the ankle is so often associated with some fracture, that the reader must be asked to refer also to the complications of Pott's fracture.

Uncomplicated dislocations practically only occur forwards or backwards; upward and lateral dislocations of the astragalus are nearly always associated with some fracture of bone, and all the types occur in association with Pott's fracture.

Backward dislocation must be fully reduced if a satisfactory functional result is to be obtained, otherwise the anterior edge of the tibia will block dorsiflexion.

To reduce a posterior dislocation when working single-handed, let the foot project over a stool or chair. A roller towel or strong bandage loop is drawn over the lower end of the upper part of the tibia, and traction applied with the surgeon's foot in the other end of the loop, while the patient's heel is drawn forward (Fig. 312).

Diagnosis is not difficult, as an undue prominence of the anterior edge of the tibia will be observed and differences on the two sides in the measurements from the malleoli to the heel and the great toe.

Anterior dislocation of the ankle. Care must be taken to determine the relative position of the various parts of the foot, for the astragalus alone may be projected forwards, or it may be fractured and half of it projected forwards, producing a hump on the dorsum of

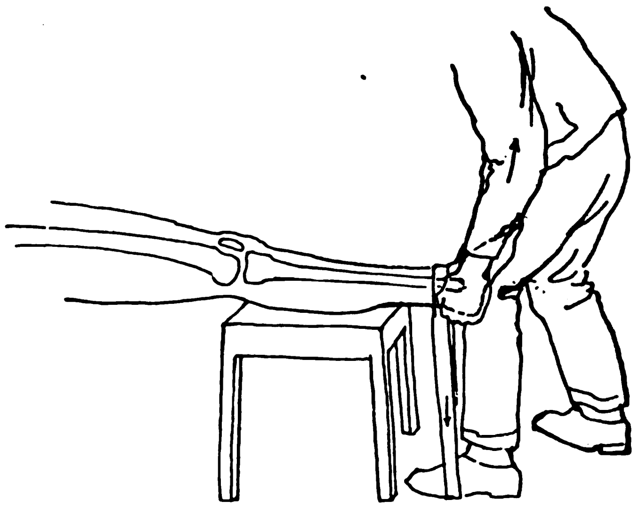

FIG. 312. DIAGRAM SHOWING FOOT IN LOOP WHEN LIFTING ANKLE FORWARD.

the foot. A simple dislocation of the ankle forwards should be reduced, but, as will be seen below, fractures of the astragalus with displacements often call for prompt operative attack.

The foot must be brought to a right angle with the leg, and a good functional result may be predicted.

Inversion of the foot. It may be correctly stated that an adducted foot is associated with strength, and that an abducted foot will be weak and become associated with flat-foot and strain of the longitudinal arches.

If the foot is slightly adducted at the ankle the body weight will fall on its outer edge, and the astragalus will be forced on to the bony angle formed by the internal malleolus and the under surface of the tibia.

If the foot is in the valgus position, the upward force is against the external malleolus, tending to spread the fibula from the tibia and producing a strain of ligaments and a painful ankle, which is often falsely diagnosed as 'rheumatic' when the whole trouble is mechanical.

Rule. In all fractures about the ankle, the foot should be placed at right angles to the leg and slightly in the varus position. If this be done, whether ultimately mobile or stiff, the foot will carry weight well.

After-treatment. After all such injuries of the ankle and after Pott's fracture, the heel of the boot should be 'crooked' on the inside, by making it a third of an inch higher on the inside than on the outside. If there is any tenderness or liability to strain, an outside iron and brace will often make all the difference between a man being able to do his work or not (Fig. 308).

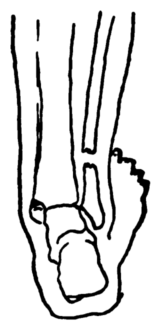

FIG. 313. POTT'S FRACTURE. Showing typical deformity and weak position of ankle.

Pott's fracture. The importance of Pott's fracture lies not so much in the break of the fibula as in the disturbance of the axis of the ankle-joint which is liable to follow.

The deformities commonly associated with the injury are eversion of the ankle and posterior displacement of the astragalus. The former, if not fully corrected, leaves the patient with a valgus deformity of the ankle. The upward thrust of the astragalus falls on the space between the fibula and the tibia instead of fairly on the tibia (Fig. 313).

Backward displacement, when not fully corrected, means that when the patient tries to dorsiflex his foot in walking, the dorsum of the neck of the astragalus will impinge on the anterior edge of the tibia.

The mechanism of the fracture is always violent eversion of the foot. The patient falls to the side of the injury with the foot caught. The thrust of the astragalus comes on the external malleolus, the strong tibio-fibular ligaments hold fast and form a fulcrum, and the thin part of the shaft breaks by leverage two or three inches higher.

Diagnosis.

1. The everted position of the foot.

2. Tenderness at the site of the fracture elicited by running the finger down the fibula.

3. Tenderness at the same point, when the upper third of the tibia and fibula are squeezed towards each other.

4. The foot is often in a slight equinus position, and displaced backwards, the outer and lower border of the tibia presenting prominently.

Treatment.

1. The knee should be flexed and counter-extended.

2. The posterior displacement of the foot should be corrected by pulling the heel forwards and pushing the tibia backwards.

3. The foot should be inverted slightly to over-correct the valgus and dorsiflexed to a right angle (Fig. 314).

After-treatment. Pott's fracture has been generally looked upon as a most disabling accident, and many surgeons of experience complain that perfect function is rarely restored to the ankle. The sources of failure are twofold: incomplete reduction and inefficient after-treatment. To secure good reduction the correction should be immediate in spite of swelling or bruising, and conducted on the lines indicated above.

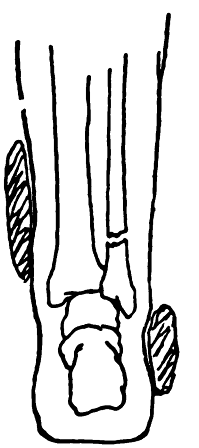

FIG. 314. POTT'S FRACTURE. Showing position of pads to restore curve of fibula and balance of ankle.

The after-treatment is often inefficient in spite of good reduction, the deformity of eversion and abduction resulting. The fracture has united with the foot and ankle in good position, but under the strain of weight-carrying the callus begins to yield and the astragalus is allowed to thrust the external malleolus outwards, and so a painful traumatic flat-foot is produced. To prevent this it is necessary that walking should be abstained from until the union is firm, and when it does take place, that body-weight should not be erroneously deflected upon the ankle. It is wise to maintain fixation of the fracture for about six weeks, and when the time for walking comes, the boot of the patient should be altered in order to keep the foot inverted, and in heavy folk a light steel brace should be applied to help the action of the boot. The toes should be kept turned in during walking from the first (Fig. 308).

In old cases where either eversion, backward displacement, or both exist, a well-planned operation will restore function.

Common complications. The following series of complications are common to cases of Pott's fracture, dislocations, and some so-called bad sprains:

1. The tip of the internal malleolus is generally torn off by accident—treatment in full inversion meets this.

2. Where the accident is caused by a fall or jump from some height, the astragalus may be forced up between the tibia and fibula, driving before it a wedge-shaped portion of the tibia. Strong traction on the foot and inversion will get the astragalus down between the malleoli, and generally the wedge will follow it, for some fibres of the ligamentous attachments between it and the astragalus will remain.

3. Fracture of the anterior edge of the tibia is very important, because it is frequently overlooked. The separated fragment slips down in front of the joint and blocks dorsiflexion, a disability which is very crippling to the patient. This disability ought never to occur, for the surgeon ought always to dorsiflex the foot when readjusting an injury about the ankle, to ensure free right of way (Fig. 315).

If diagnosed, the foot should be first extended and the fragment pushed into place, then the foot is dorsiflexed. If the fracture is not discovered until the union is firm, it will be necessary to operate. The

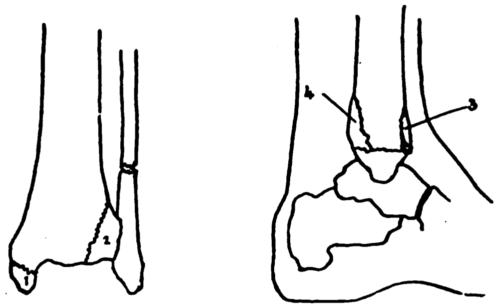

FIG. 315. POTT'S FRACTURE. COMMON COMPLICATIONS. 1. Fracture of internal malleolus. 2. Fracture of anterior wedge of tibia associated with upward displacement of astragalus. 3. Fracture of anterior edge of tibia. In a large proportion of cases the foot and astragalus are dislocated backwards and outwards.

projecting end of bone should be sufficiently chiselled off to admit of dorsiflexion.

Dislocations and fractures of the astragalus. Dislocation of the entire astragalus forwards is produced by violent plantar flexion of the foot. The injury is frequently compound.

The diagnosis is obviously made by the hump on the dorsum of the foot, by altered relations of the bony points.

Associated fractures of the malleoli or of the astragalus may be detected by manipulation and will be recognized in the X-ray photograph, which should never be omitted.

Fractures of the astragalus occur most commonly in heavy falls on the feet, when the astragalus may give way instead of the lower ends of the tibia and fibula. The fracture may be transverse, most usually where the body joins the neck, or the line of the fracture may be antero-posterior, splitting the body into two lateral portions.

At one time teachers of surgery laid great stress on the blood supply of bone, and pointed out that once the astragalus was torn from its connexions with the os calcis, necrosis might be expected. This ancient teaching is false. Bone cells have extraordinary vitality, and can survive if only some of the natural fluid effusions of the body can percolate to them. This is amply proved by modern osteoplastic surgery. Bone cells, however, die rapidly in the presence of poisonous products of bacilli, for the osteoclasts cannot open up the Haversian canals rapidly enough to establish a protective hyperæmia. Hence the conjunction of an impaired blood supply and toxic products are fatal to bone, and the only chance of saving it is drainage, sufficiently prompt to prevent the toxic products from collecting, and so allowing the processes of repair to establish themselves.

Bearing these facts in mind, we may assume that if the astragalus can be got back into good position, a good result may be expected in the absence of sepsis, and is worth an attempt if the septic processes can be kept under control.

Forward dislocation of the whole or of part of a fractured astragalus may be reduced. While an assistant presses the displaced bone backwards, the surgeon exerts traction on the foot to separate the os calcis and tibia. There should be no hesitation about dividing the tendo Achillis to get more room. If the astragalus can be got to engage between the os calcis and tibia, dorsiflexion of the foot may cause it to shoot back into place. If the foot can then be put easily at a right angle to the leg, all will be well.

In cases of transverse or longitudinal fracture, the same line of treatment is to be followed. Once the bone can be got into position between the malleoli, all the surgeon needs to consider is the future usefulness of the foot for carrying weight, and important factors in connexion with flat-foot must have due regard paid to them.

In many cases of displacement of part of the astragalus and in some cases of dislocation of the whole bone, the displaced bone gets turned round in such a way that no manipulation will again twist it into position, when it should be removed.

In transverse fractures of the astragalus the posterior portion is generally displaced backwards and interferes with the tendo Achillis. This portion may be removed, leaving the anterior part *in situ*, with the foot fixed at a right angle. Effusion takes place into the vacant space, which becomes to some extent organized, and a very serviceable ankle results if the part is protected from strain till repair is well advanced.

Fracture of the neck of the astragalus. The after-treatment of a fracture of the neck of the astragalus, as distinct from a fracture of the body, depends on a proper grasp of the architecture of the arches of the foot, and the distribution of the body weight on these arches. The human foot consists of two portions:

(*a*) A posterior portion, consisting of the astragalus and os calcis, which we shall call the hind part, and is situated behind the mid-tarsal joint, or so-called Chopart's joint.

(*b*) An anterior portion consisting of the rest of the tarsus, the metatarsus, and toes, which we shall call the fore part of the foot, and is in front of the mid-tarsal joint.

The hind part is quite capable of bearing body weight.

The fore part gives the foot its spring and plays an important part in balancing. The foot is a tripod resting on three points: the heel, the ball of the great toe under the head of the first metatarsal, and the heads of the fourth and fifth metatarsals.

It has a transverse arch, with which we are not here concerned, and two longitudinal arches.

The outer longitudinal, which is less arched than the inner, consists of the os calcis, cuboid, and the fourth and fifth metatarsals, and is not particularly liable to strain—in fact, with any weight on the foot the whole of the outer edge of the foot is on the ground.

The inner component of the longitudinal arch is much higher, and strain of this arch constitutes flat-foot. It rests behind on the os calcis and springs upwards and forwards through the astragalus to its summit, and then downwards, forwards, and *inwards* through the scaphoid cuneiform and first metatarsal to the ball of the foot under the great toe.

The true crown of this arch is in the neck of the astragalus, which is set at an angle, downwards and *inwards* from the body. Hence if the neck is fractured, the effect of putting undue strain on the new callus is to strain it exactly as the astragalo-scaphoid joint is strained in a flat foot.

Hence to protect it the patient should have an outside brace with T-strap and a well-crooked heel, to deviate body weight on to the outer side of the foot until the callus is strong enough to carry weight without being strained, just as if the patient suffered from acute flat-foot (Fig. 308).

Flat-foot, everted foot, and **weak foot** have been applied to various degrees and stages of the same mechanical derangement of the foot, though orthopædic surgeons have not arrived at a definite agreement as to what precise meaning is to be attached to each term. The names matter little, the ideas conveyed by the varied nomenclature are important, for they give a general view of the subject.

The foot of the infant is distinctly adducted and inverted at the mid-tarsal joint—really at the neck of the astragalus, but we need not elaborate that point; the child of two or three years walks with his feet parallel. The Red Indian, who wears moccasins, and barefooted races preserve the plumpness of the infant foot, and walk with the feet parallel. Civilized man—so called—wears pointed boots, turns out his toes, abducts and everts his foot at the mid-tarsal joint, and really strains this joint and so paves the way for the production of flat-foot.

The plumpness of the foot in barefooted races and the infant is due to full development of the small muscles, which act on the 'fore part' of the foot.

The ugly attenuated foot of boot-wearing races is due to atrophy of these muscles, caused by squeezing the fore part of the foot into a boot which allows no play.

The maintenance of the arch depends on the muscles and the ligaments. Ballet-dancers who have strong muscles and can pirouette on their toes are frequently flat-footed because in the positions of extreme eversion of the foot which they practise they stretch the ligaments under the inner arch of the foot. Hence when they rest, relaxing the muscles, the ligaments are too stretched to maintain the arch, and the foot looks and is flat. The joints are free and the muscles strong, and so the spring of the foot is maintained. The flat-foot of one who stands all day is different: his muscles are weak, the foot has remained flat and has become stiff in the flat position. Ultimately he has a painless, stiff flat-foot and no spring in the arch, but before he reaches this stage he passes through various painful stages of weak foot to his final condition of flat-foot. *Pain* in flat-foot is mainly due to stretching of ligaments. All the ligaments about the tarsus participate, but strain of the inferior calcaneo-scaphoid ligament is characteristic of the foot which is *becoming flat*. At this stage the foot is not actually flat, and footprint records are of little value, for the normal arch varies greatly in different individuals; hence a person with a naturally high arch suffers more than one with a naturally low arch, without any visible flatness to account for it.

Diagnosis.

1. Pain in the instep across the dorsum, or all over the foot, according to how many of the ligaments are suffering strain.

2. When the patient stands to attention his muscles may pick up the arch and the deformity become less evident, but as the muscles relax he stands with feet everted and the tuberosity of the scaphoid descends.

3. On palpation, tenderness is found under the tuberosity of the scaphoid, due to strain of the inferior calcaneo-scaphoid ligament.

4. In cases with severe eversion, pain is complained of on the outer

side, due to the os calcis impinging on the tip of the malleolus. It may be due to periostitis, or an adventitious bursa may form.

5. In acute cases the whole foot becomes painful to touch or movement.

Treatment. Ordinary cases of painful feet due to an unaccustomed amount of walking, or narrow boots which do not leave room in the fore part for the play of the small muscles, will generally be found to have the characteristic tenderness under the tuberosity of the scaphoid. This demands rest of all the structures on the inner side of the foot. This can be obtained by deviating the body weight on to the outer border of the foot.

Boots should be straight on the inner border and roomy in the fore part, but should grip the 'hind part' comfortably to prevent chafing and blistered heels. The heels of the boot should be a third of an inch higher on the inner than on the outer side to tilt the body weight on to the outer edge of the foot. (Fig. 308.)

Instep-plates are radically unsound, as they compress the small muscles of the sole between the plate and the bones of the foot, and so prevent them from exercising themselves and getting strong. They will do this naturally if relieved of undue strain.

The patient should practise movements:

(*a*) Free inversion movements of the foot and all movements of the toes to strengthen the small muscles of the foot and the tibials.

(*b*) Tiptoe exercises, coming down on the outer edge of the foot—never down in the flat-foot position.

Contrast-bathing by plunging the foot rapidly in hot and cold water alternately is a great stimulus to the circulation and will prevent the muscles from getting cramped and stiff.

All these points are of value in training and hardening recruits. In ninety-nine cases out of a hundred pain in the feet is mechanical strain, not 'rheumatism'; and if the recruit's boots were raised on the inner side of the heel he would be very rarely off the parade ground.

The above line of treatment is applicable to all cases in which the patient can voluntarily invert his feet and walk on the outer edge.

In stiff flat-foot he cannot do so for mechanical reasons; in acute flat-foot pain prevents it.

Acute flat-foot is due to sudden straining of all ligaments about the tarsus; the whole foot and tarsus becomes acutely tender and somewhat swollen. It may come on by injudicious exercise; it is common, for example, in nurses who are sent on duty too soon after an illness.

It may come on after a foot has been crushed or after a sprained ankle.

Here there has been an injury associated with effusion which has softened and loosened ligaments. After a few days' rest the patient feels better—goes for a long walk before his ligaments have hardened up, and develops an acute flat-foot. In cases of unilateral flat-foot there is nearly always a history of accident to the affected foot, it may be weeks before.

Treatment.

1. Complete rest in bed and massage to get rid of swelling.

2. A week in plaster of Paris with the foot fully inverted to let all stretched structures shorten.

3. Commence exercise and wear boots with crooked heels, walk with feet parallel exactly as has been described above.

Rigid flat-foot may be—

1. The end stage of an untreated flat-foot of purely static origin.

2. The final stage of a crushed or injured foot which was not bandaged in the inverted position and treated as described above.

3. The final stage of an arthritis or a gonorrhœal periarthritis, where the patient has walked on the foot before the ligaments were strong.

Every general injury of the foot—crushes, fractures, &c.—should be protected against becoming a flat-foot by not letting the patient walk until he has had the heel of the boot crooked to deviate weight to the outer side, and if the injury has been severe, an outside brace as well.

Treatment of rigid flat-foot. The treatment is to convert the foot into an acute case by giving an anæsthetic, breaking down *all* adhesions with Thomas's wrench (Fig. 300). It is no use breaking down only some of them. The foot must be wrenched in every direction, till it is perfectly pliable; then put in plaster for ten days in the inverted position; after that the patient starts walking in a boot with crooked heel, and can generally return to light duty in a month after the foot is wrenched.

A common type of flat-foot is due to spasm of the peroneus longus and brevis muscles, probably the result of strain at their insertion. It presents all the appearance of an osseous flat-foot; the foot is quite rigid and voluntary inversion cannot be performed, but under an anæsthetic the deformity disappears. Such cases are troublesome, and are best treated by excision of half an inch of both tendons just above the external malleolus, followed by inversion of the foot with adduction at the mid-tarsal joint and fixation in plaster for a fortnight. The subsequent treatment is the same as that for ordinary flat-foot.

Alteration of boots, with or without braces, are of no avail in rigid forms of flat-foot until the patient's foot has been forcibly inverted.

Hallux rigidus. This affection is proving a source of considerable trouble amongst our recruits. It consists, as its names implies, of a stiffness of the big-toe joint accompanied by pain.

The first objective symptom is an obstruction to full extension of the joint, which, as the disease progresses, results in fixed flexion at the metatarso-phalangeal joint. Swelling may not be present, but sometimes there is lipping of the bones, and it is often associated with flat-foot.

It may be produced by 'stubbing' the toe or by a direct blow, but usually comes on gradually, and is often associated with a strained foot which is becoming flat. In an unconscious effort to save the arch the patient attempts to maintain it by digging his great toe on the sole of his boot. The joint may become very tender, and in old cases quite stiff. When marching the soldier cannot get off his toe as he steps off, because he cannot dorsiflex it.

Fig. 316. Bar across Sole, behind Tread.

Treatment. A bar across the boot about half an inch thick just behind the head of the metatarsal makes the neck of the metatarsal bear the body weight instead of the joint (Fig. 316).

In later stages where the joint is very tender it is more satisfactory to excise the head and form a pseudarthrosis by covering the head of the bone with subcutaneous fascia or the bursa. Such a false joint restores the function of the foot.

Hallux valgus. Hallux valgus is an outward displacement of the great toe. It may give rise to very crippling symptoms, or it may not even be inconvenient. The joint may stand an ordinary amount of strain, but disable the recruit on long marches.

In extreme cases considerable alteration in the relationship of the bones of the metatarso-phalangeal joint may take place. As the phalanx travels to the outer side, the head of the metatarsal becomes partly uncovered and enlarged, with irregular edges due to periosteal irritation. The skin over this prominence becomes thickened, and the bursa inflamed. It is the inflammation of this bursa which gives rise to the painful symptoms sometimes culminating in a cellulitis.

The simple case, as in hallux rigidus, can be dealt with by placing a bar across the boot-sole (Fig. 316), but the severe case requires operation, which should not be undertaken until all inflammatory symptoms are in complete abeyance. A pseudarthrosis of the joint should be the aim, when the bursa can be placed over the metatarsal bone after the head and neck are exsected, or a thin slice of the head with its cartilage can be applied to the metatarsal after the removal of the neck; thus a good weight-bearing joint may be secured.

Excision of the joint is advised by some surgeons. This operation is not a success when performed.

Hammer-toes, which give rise to marked disability and often prevent the patient from completing route marches, should never be amputated, as this leads to secondary deformities. An elliptical incision should be made over the angulation, and the skin and bursa removed; then a wedge from the phalanges should be removed sufficiently large to permit of correction of the deformity, and the toe is allowed to ankylose in a straight position.

Metatarsalgia. This affection is characterized by a cramping pain, more or less spasmodic, situated below the metatarso-phalangeal joint of either the second, third, or fourth metatarsal heads, much more generally the fourth.

It is due to a flattening of the transverse arch and pressure upon the twigs of the external plantar nerve.

The treatment, if radical, is effective—it should consist of removal of the painful metatarsal head.

Palliative treatment should consist in placing a bar of leather across the boot under the tread, just behind the heads of the metatarsals.

MALPOSITION OF JOINTS AFTER AMPUTATION

During the recovery of stumps after amputation, care should be taken to procure a free range of movement in the neighbouring joints. Otherwise difficulties will arise when the time comes for fitting artificial limbs. This is especially important in the hip and shoulder. Quite a large proportion of cases are returned with flexion at the hip, which can only be accurately detected by flexing the sound limb on the patient's chest, when it will be found that the stump cannot be fully extended; in other instances there will be limitation in abduction, adduction, or rotation. The shoulder may be similarly handicapped after amputation through the arm. To prevent this, the position of the stump should be frequently changed during healing—a process so often delayed by suppuration—and, in addition, the joint should be put through its full range of movements two or three times a week. Deformities which have been allowed to take place during recovery will require complete correction before an artificial limb can be effectively worn.

If deformity is threatened by contraction of scar tissue, it is imperative that the limb be placed for an extended period in a position opposed to the pull of the scar.

SECTION IX

TREATMENT OF JOINT AND MUSCLE INJURIES

BY

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CHAPTER I

INTRODUCTORY

I HAVE thought it well to commence with an account of the method of Graduated Contraction and its uses, for the keynote of the treatment in both chronic and acute cases of injury, as outlined in the following pages, lies in the treatment of the muscles.

The results of the treatment of muscle wasting and of muscle insufficiency are good, and I am certain that, as this method becomes more widely known, it will be recognized as the ideal method for the routine treatment of these conditions whenever circumstances permit.

The method consists in this—the muscle is stimulated to contract by an induced (faradic) current, and the contractions are exactly graduated both as regards degree and rhythm by the operator.

In so far as the stimulus is a battery current the method is an electrical one, but the restoration of muscle tone, the essential factor in producing recovery, is brought about by the muscular contractions themselves, and not by the electricity *per se.*

The current is used to make the muscle contract to any desired extent, from the minimal to the maximal degree, which the particular muscle is capable of, and there its use ends. There is no question of giving electricity, or of passing currents through the muscles. Any general effects of electricity on the patient may be entirely disregarded.

Muscular contraction is what is wanted to restore muscle tone, and with it muscle function. Given an intact nerve-supply, contractions can be obtained in muscle, no matter how wasted.

The contractions brought about by this form of stimulus simulate very closely normal physiological contractions. To so great an extent is this the case that anyone seeing a patient under treatment, and observing that his joint was being moved by the action of his own muscles, would suppose that the movements were voluntary movements and under the patient's own control.

As an instance of this, if the leg is allowed to hang over the edge of a couch with the knee flexed—all the muscles being relaxed—and the quadriceps be stimulated, contraction of that muscle group is followed by extension of the leg at the knee-joint, exactly as though the patient himself were performing a voluntary movement.

Now a point of very great importance in this connection is that, although the wasting may be so profound that the patient cannot voluntarily contract the affected muscle group, yet contractions can be brought about by this method of stimulation.

And further, as a direct result of this, the muscle tone is gradually restored, until the muscle shortens to such a degree as to enable the patient to produce contractions voluntarily.

In these cases of muscle wasting it has become the fashion in recent years to advise massage. Now treatment by massage alone is very tedious and very slow in producing a good result. It is no uncommon thing for a patient to give a history of from four to six months' disability from insufficiency of the quadriceps, and to have had treatment by massage during the greater part of that time.

I have had cases brought to me in which long courses of massage treatment have entirely failed to build up the wasted muscle, and some such are quoted in the following pages.

Of course, the treatment by means of active exercises against graduated resistance will build up muscle, but this method is not applicable to the worst cases.

Until a muscle can be voluntarily contracted by the patient, how can it be exercised? In my experience even the so-called assisted exercises are of but little service when the atrophy is very marked; but this whole question is discussed more fully in the last chapter.

Moreover, it is there pointed out exactly at what stage in treatment exercises can be used with advantage, gradually replacing at first, and with advancing recovery ultimately supplanting this more specialized method.

Mr. J. E. Adams, in an article in the *Practitioner* in 1915, came to a similar conclusion as the outcome of seeing the results of treatment by the various methods as practised at St. Thomas's Hospital.

All the structures which form part of a joint are necessary for its normal function: bone, cartilage, synovial membrane, ligaments and muscles, and in certain joints intra-articular fibro-cartilages in addition.

Depending on the severity of the lesion, any or all of these structures may be damaged to a greater or less extent, but in every case the musculature suffers.

On this important fact, nothing like sufficient stress is laid. As a result of joint injury, or, for that matter, joint disease, the muscles which normally control the movements of that joint waste. Moreover, this wasting is, if one may use the term, 'active'—it is not simply wasting from disuse.

The explanation of this lies in the fact that the joint and the muscles

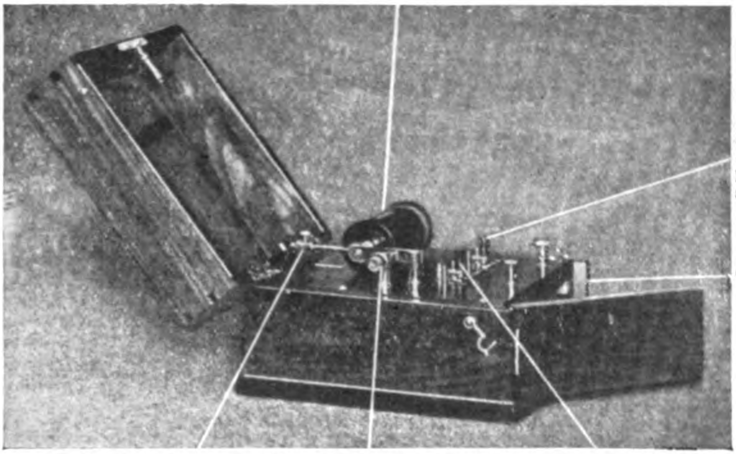

FIG. 317. BATTERY. SIDE VIEW.

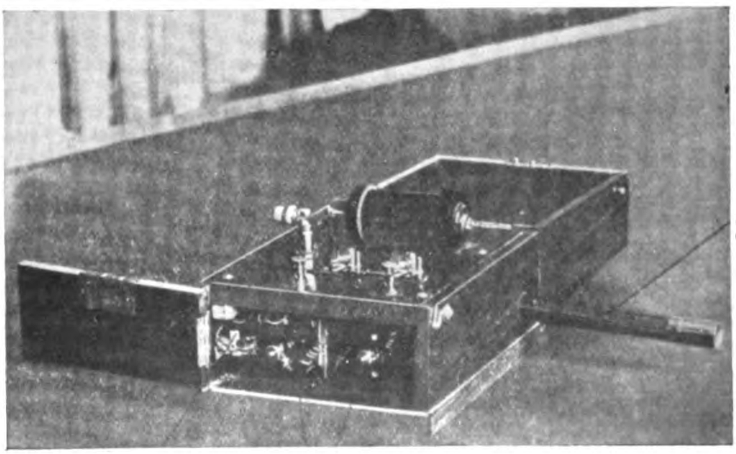

FIG. 318. BATTERY. END VIEW, SHOWING CORE WITHDRAWN.

which normally control its movements are supplied by the same nerves. In other words, the wasting is reflex.

In the case of the knee-joint this wasting is most marked in the vastus internus. The nerve to the vastus internus supplies by far the largest articular branch to this joint, which appears to be the explanation. With injury to the shoulder-joint, the wasting is most marked in the deltoid.

In the case of a joint undamaged and kept at rest for some other purpose, the muscles will not show anything like the same degree of atrophy as will those of an injured joint under similar conditions.

Both the shoulder and the knee are far more dependent for their strength and security on the muscles than on the ligaments, excepting, of course, the crucial ligaments in the case of the knee, and these structures are, fortunately, but rarely damaged.

In the case of the ankle and wrist, excluding complete rupture of a lateral ligament, restoration of muscle tone is accompanied by complete return of function, and I do not think sufficient stress is laid on the importance of the muscles to the integrity of either joint.

In cases of joints almost entirely dependent on the ligaments for their strength, such as the sterno-clavicular, or acromio-clavicular, naturally the importance given here to the state of the muscles cannot apply to the same extent.

Now it is essential to the proper carrying out of the treatment that the patient be absolutely relaxed. If he is receiving painful stimuli this is impossible.

It is quite impossible to carry out treatment by this method, using the ordinary faradic coil, as supplied by the instrument makers, on account of the fact that the stimulus from such a coil is painful—due to the so-called ' faradic effect ' on the skin. This tingling, pricking sensation becomes marked as the current's intensity is increased, and the patient is sure to resist.

The battery recommended consists of a specially wound coil, actuated by dry cells, or by accumulators. The primary and secondary windings are both of thick wire. The secondary, which is the current used, can be tapped from either one, two, or three layers, depending on the strength required.

The interrupter must be quite regular in action, and there should be no visible spark at the make and break; a condenser is placed in the circuit for this purpose. The coil is one which yields a secondary current of very low voltage and which is practically painless.[1]

[1] A satisfactory coil is now made by Messrs. Schall and Co., New Cavendish Street, after prolonged experiment.

FIG. 319. GRADUATED CONTRACTION—1ST STAGE. POSITION OF REST. Note position of soft iron core fully withdrawn, and the weight of the arm, supported on a pillow, with all the muscles completely relaxed. Notice position of hand grasping the electrode and the muscle.

FIG. 320. 2ND STAGE. SLIGHT CONTRACTION. Note partial insertion of core, and commencing contraction in the deltoid.

FIG. 321. 3RD STAGE. COMPLETE CONTRACTION OF DELTOID WITH ABDUCTION OF ARM. Note that the core is pushed well in.

The intensity of the stimulus is varied at will by pushing in and withdrawing the soft iron core in the primary coil.

When the core is fully withdrawn, there is no contraction, although of course the current is passing. As the core is gently pushed in the muscle commences to contract, and as it is withdrawn the contraction passes off.

The contraction is perfectly controlled from minimal to maximal, and the amount of contraction is in direct ratio to the degree of insertion of the core.

Any degree of contraction can be obtained, from the slightest tremor of the muscle fibres followed by relaxation (as in the treatment of an acute lesion in the early stage) through the stage in which the tendon is made to stand out prominently without movement of the joint on which it exerts traction, to the complete contraction of the muscle belly, with the tendon standing out prominently and movement of the joint; that is, every degree of contraction, and each degree controlled absolutely by the operator.

If the core is gradually inserted until the muscle contracts to its maximum and then equally gradually withdrawn, the contraction will pass off just as gradually.

This graduation is the keynote of the method. Everyone knows that a faradic current applied to a muscle will cause contraction in that muscle, but repeated and haphazard stimulation, although producing contraction, will not in practice produce the restoration of muscle function, which is the result aimed at.

Another method which I have used in a considerable number of cases for the regeneration of wasted muscle, especially at St. Thomas's Hospital, and which I employed as a labour-saving device, consists in leaving the core sufficiently inserted to cause a considerable degree of contraction, and to effect sudden contraction and relaxation by making and breaking the secondary current *via* a metronome. Every time the cross wire on the metronome dips into the mercury cup, a contraction occurs and passes off as the dipper breaks contact.

We have found in practice at St. Thomas's Hospital that to restore tone and function to a wasted muscle group by this method takes from two to three times as long as when the graduated method is used, and the core gently and gradually inserted and withdrawn by hand.

This is interesting as helping to prove that the Rhythmic Graduated Contractions are the form of stimulus to which the muscle reacts best.

CHAPTER II

THE TECHNIQUE OF THE TREATMENT BY GRADUATED CONTRACTION

In order to make the treatment by this method clear, I will proceed to describe in detail the actual treatment of a muscle group, and will take the quadriceps as an example. With the obvious alterations in the position of the pads and so forth, the description is equally applicable to any other muscle or group of muscles.

The patient is placed on a low bed or couch with the lower extremity

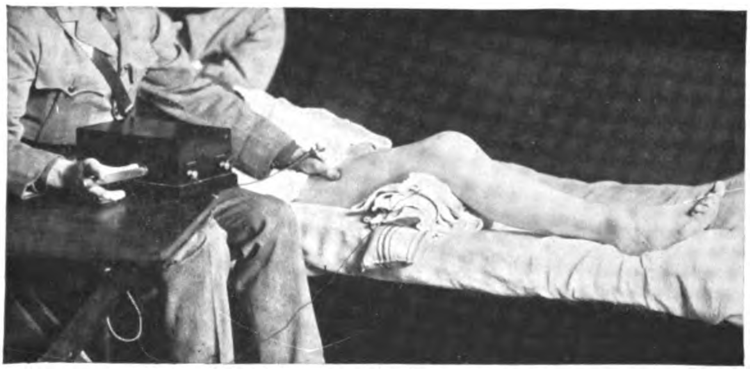

Fig. 322. Position for Stimulating Quadriceps. Knee semi-flexed over sandbags and all muscles fully relaxed.

bare. It is not enough to turn up loose trousers, as it may be necessary to stimulate high up the thigh.

The affected limb has a sandbag placed under the semi-flexed knee in order that it may lie absolutely easily and at rest, and between the knee and the sandbag, and held in place by the latter, is placed the indifferent electrode. This is a metal plate, roughly, five by four inches. This is attached to one terminal of the battery, and of course it does not matter to which. The plate is covered with two or three layers of lint, made wet (and not merely moistened) with water, to which a little salt has been added.

The other electrode, the active, a small metal disc about the size of a five-shilling piece, covered with lint and made wet, is grasped in the cleft between the thumb and first finger of the operator's left hand.

The operator sits at the patient's right side with the battery on a small table in front of him. Everything must be so arranged that he can work the core of the coil with his right hand, and comfortably reach the patient's muscle with his left.

The active electrode is placed in contact with the quadriceps at a point

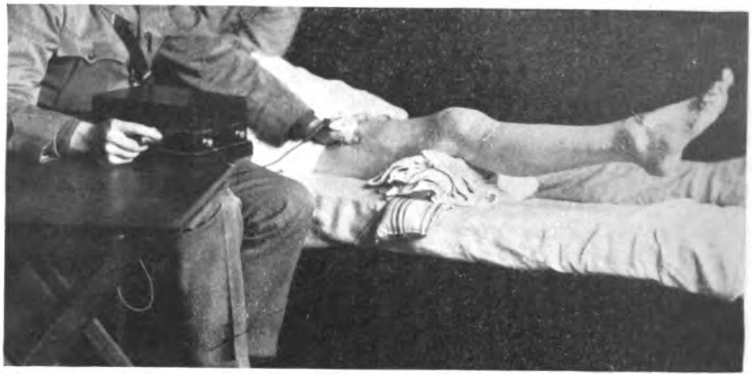

FIG. 323. STIMULATION OF QUADRICEPS WITH EXTENSION OF THE LEG. In this case the patient was totally unable to make any voluntary extension on account of the complete wasting and lengthening of the quadriceps from loss of tone, arising from knee injury.

about the mid-line of the thigh in front, at the junction of the upper and middle thirds.

This is the common point of stimulation for the rectus, crureus, and external vastus.

The electrode is placed on the muscle, and the muscle substance is grasped, together with the electrode, between the thumb and first finger.

These instructions may seem somewhat laboured, but it is necessary to feel the amount of contraction, and I have seen so many people fail to grasp the meaning and significance of this simple point that it cannot be too strongly insisted on.

The right hand gradually inserts the core whilst the left appreciates the amount of contraction. The core should be inserted and withdrawn evenly and rhythmically at a rate of about seventy times a minute. The degree of contraction being thus exactly controlled and appreciated, such a degree as is deemed necessary can be obtained.

If the muscles are much wasted, the leg will not be raised from the couch by the contraction, for the wasted muscles will be lacking in tone and incapable of a normal degree of contraction. But the muscle will be felt to contract by the operator's left hand, the patella will be drawn up slightly, and the ligamentum patellæ rendered tense.

If the wasting is slight, the action of the quadriceps will produce rhythmical extension of the leg.

When this portion of the quadriceps has been treated for some two or three minutes, it should be allowed to rest, and the two other important muscles should be dealt with in turn, viz., vastus internus and the tensor fasciæ femoris.

The point of stimulation for the vastus internus is an inch or two above and just internal to the lateral border of the patella. When this muscle is contracted it will be seen to have little or no action in raising the patella. It is, in my experience, the muscle that wastes most rapidly and most completely in injuries of the knee. The vastus internus, or rather its lower fibres, appear to act largely as a support to fix the knee, and form a strengthening buttress for the inner part of the capsule and very little as an extensor.

This may also account for the fact that active exercises against resistance—as in the 'stationary bicycle' and various forms of Zander apparatus—have far less effect in restoring the vastus internus than they have on the other members of the quadriceps group.

By Graduated Contraction the tone of this muscle is restored and function regained as easily as is that of the other muscles, and the treatment therefore presents no difficulty.

The tensor fasciæ femoris is the other important muscle to exercise in these knee cases. It can be put in action by stimulating at the outer margin of the thigh in the upper third. It will be obvious when the right point is reached, as the fascia lata (ilio-tibial band) stands out strongly each time the muscle is made to contract.

The tensor fasciæ femoris is of the utmost importance in supporting the body-weight in the upright position and with the minimum of effort, and it should be treated regularly and systematically at each sitting. I do not think enough importance is attached to this small muscle in treatment of wasted quadriceps as a rule, and it is difficult to get at by massage and not easy to exercise.

The treatment of the whole quadriceps group, with a minute or two spent on the adductors, takes about twenty minutes in an average case, but it is not possible to lay down hard and fast rules as to the amount of stimulation required, as this varies with each case.

No one point is stimulated for so long a time as to induce fatigue in the muscle. The signs of oncoming fatigue are not easy to describe, and this whole question of fatigue is of great importance. If the muscles be over-exercised, the patient will next day complain of stiffness

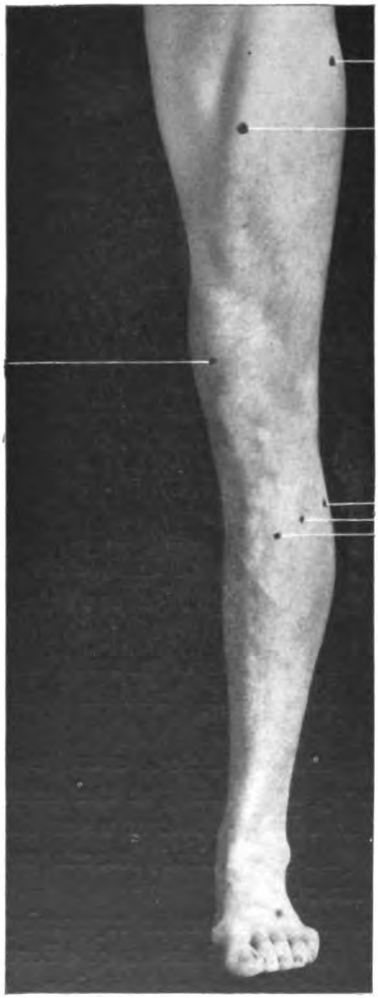

FIG. 324. ACTUAL POINTS TO BE STIMULATED IN TREATING THE MUSCLES OF THE LOWER EXTREMITY.
a. Tensor fasciæ femoris.
b. Common point for main extensor.
c. Vastus internus.
d. Tibialis anticus.
e. Extensor longus digitorum.
f. Peronei.

and aching, and recovery is retarded.

A markedly wasted muscle group is stimulated for less time than a more normal one, and the actual contractions should always be submaximal. This degree of contraction is gradually increased from day to day as the muscle recovers tone with treatment.

Experience and the handling of cases alone can guide one as to the amount of treatment which is necessary for any particular case.

It is infinitely better to do too little than too much. The only sign I know of that the muscle has done as much work as is desirable is that the character of the contraction tends to change. In place of the firm physiological contraction of the whole muscle, one sees rather a local contraction in the neighbourhood of the stimulating electrode, and a tremor or irregular contraction beginning to result from the stimulation.

After the main quadriceps (rectus, vastus externus, and crureus) has been dealt with for a minute or so, the vastus internus is stimulated, then the tensor, then the quadriceps again, and so on.

There is one practical point to mention here, and that is, do not stimulate too far over to the inner side without caution. The marked contraction of the main group, with free insertion of the core necessary to produce it, is painless; but if the active electrode is taken over to the inner side and as strongly stimulates the sartorius it will cause pain.

The sartorius reacts more readily, in other words, gives its maximum contraction to a less stimulus, and so may be overstrained and give rise to pain if carelessly or too vigorously dealt with.

During the treatment the patient must be absolutely relaxed. Then the treatment is painless. If he should strain at all, it at once gives rise to pain. Never stimulate if he moves, and if he moves or strains whilst the contraction is being produced at once allow the muscle to relax by withdrawing the core. With a little practice the control is so perfect that even with a nervous patient the whole treatment can be carried out painlessly.

The tone is improved in one sitting, and an amount of contraction impossible at the start may be quite easily produced after a few minutes and the joint moved by the active contraction of the muscle. This effect is only transitory at first, and passes off in an hour or so, but lasts for a longer time after each treatment until the tone is restored permanently.

The method of treating cases is so easy after a little practice that the following instructions may seem superfluous, but I call attention to them here because I know from experience how much more quickly a case progresses if the operator is experienced, than it does if he has had but little practice in using this battery.

First, the position of the patient must be such that there is absolutely no strain or muscular effort. In treating the deltoid region or forearm, there must be no weight on the shoulder girdle—*i.e.* the arm must be supported and not simply allowed to hang down. If the lower extremities are being treated the patient lies on a couch with a support under the affected knee.

Again, after any one contraction the stimulus must be decreased until complete relaxation takes place. If the muscle is kept partly tetanized, it will waste, as has been shown experimentally.

All screws and connections with the wire and electrodes must be firm, and the electrodes themselves really wet and not simply moistened. In this way there is no waste of current, and therefore a weak current will produce the contraction. This is desirable, as strong currents naturally tend to become unpleasant, and would cause the patient to resist. As regards the position of the pads, the active electrode is always in the left hand, and applied direct to the muscle, or its motor nerve. Broadly speaking, the point of maximum stimulus is at the motor point. It must be remembered that very often—in fact, in most cases—it is a group of muscles rather than an individual muscle which is being treated.

The size of the electrode recommended obviates any difficulty.

The three main points of stimulation were noted in dealing with '*quadriceps*' cases. Below the knee the motor points suffice for the anterior muscles. The action of these muscles in moving and controlling the ankle-joint can be beautifully shown. The motor points for the tibialis anticus, extensor longus digitorum, and the peroneal nerve, winding round the neck of the fibula, for the peronei muscles are the points of stimulation.

Pure action of any of these muscles can be obtained, and in the case of the first dorsiflexion of the foot with inversion, and of the third dorsiflexion with eversion are produced.

These movements thus produced are of importance in dealing with sprains and allied injuries of the ankle-joint.

We are not dealing here with muscle nerve-testing, and it is obvious that stimulation of the peroneal nerve will cause both the peroneus longus and brevis to act. This is what is required in treatment, as in this situation in practice the two peronei go together in the movement of dorsiflexion with eversion.

The indifferent electrode may be placed anywhere. Usually it is best put under the knee in cases in which the lower limb is to be stimulated; between the scapulæ if the upper limb is being dealt with or if the erector spinæ is being redeveloped.

When treating the scapular muscles, the indifferent electrode may be placed in the lumbar region.

For the flexors of the hand and wrist, it may be placed either between the scapulæ or on the inner side of the arm, but in dealing with the extensors of the hand I usually tie it to the back of the wrist. In this situation a more complete control is given by this means, and there is better movement in treating the extensors in, say, a recovering musculo-spiral lesion or a Colles's fracture.

The electrodes should be plain metal, simply covered with a few layers of lint (not sewn on) renewed for each case. As ordinarily supplied, covered with one layer of flannel, they get dry too quickly.

In concluding these instructions on the technique employed, I wish to point out the necessity of practice with the coil.

It looks perfectly easy to contract the muscles gradually and rhythmically in any case, and so it is, but only after practice.

Jerky movements of the core and incomplete relaxation between the contractions are common faults, and I would advise a little practice with normal muscles before injured ones are approached.

In acute cases, and particularly in dealing with fractures in their early stages, the medical man himself should carry out the treatment, unless he can call upon the services of a competent and specially trained masseuse, who is thoroughly familiar with these conditions.

The redevelopment of muscle and muscle training, in which the scope for the employment of this method is so great, can well be carried out

FIG. 325. STIMULATION OF TIBIALIS ANTICUS, SHOWING INVERSION OF FOOT WITH DORSIFLEXION.

FIG. 326. STIMULATION OF EXTENSOR LONGUS DIGITORUM, WITH DORSIFLEXION OF ANKLE-JOINT.

FIG. 327. STIMULATION OF PERONEI. Notice the tendons standing out prominently behind the external malleolus. Notice the position of the leg, with the indifferent electrode held in place by a sandbag, under the semi-flexed knee, in this and the two preceding figures.

by masseuses or others trained in the use of the coil. This is now routine work in the departments of two big London hospitals, and the results are excellent and will well repay any time spent in mastering what is, after all, a fairly simple technique.

CHAPTER III

ACUTE SPRAINS

THE following chapter on acute sprains and their management is based on personal experience. It is an endeavour to outline the principles of treatment as practised by the writer in a large number of cases, extending over a period of the last six years.

In the first place, nothing like sufficient importance is attached to the treatment of this type of injury. From the patient's point of view a severe sprain is a very real calamity, and not only does he suffer a considerable amount of pain, but he is incapacitated from following his ordinary avocation for a varying period. Indeed, if the condition be neglected, this period may run on into months.

If the condition from the outset is regarded as sufficiently serious, and is treated as such, complete recovery can be attained in a reasonably short space of time, and the condition of chronic sprain, with its crippling adhesions and muscular wasting, will be obviated.

Sprains may be conveniently divided into two main classes:—

1. Those primarily involving joints, of which the sprained ankle or wrist are perhaps the commonest types.

2. Those involving muscles. This type usually occurs in athletes and people leading a hard outdoor life. The commonest situations for sprains in my experience are (*a*) the adductor group, the so-called rider's sprain; (*b*) the calf of the leg generally regarded as a torn plantaris tendon, but more probably due to a tearing of some muscle fibres of the gastrocnemius or soleus; (*c*) in the neighbourhood of the elbow, produced by any form of exercise, in which full extension with supination or pronation is frequently and violently performed, as in tennis, squash racquets, fencing, golf, &c.

Diagnosis. Before commencing the treatment of a sprained joint it is absolutely essential to form a correct estimate as to the extent of the damage.

Every case of sprain, excepting the most trivial, and especially any case in which the swelling obscures the outline of the joint, should be submitted to X-ray examination before treatment is commenced.

Some of the linear fractures without displacement are impossible to diagnose by any other means, and although the treatment may in many cases be on similar lines, the prognosis as to time, and the question of bearing weight on the limb or actively using the joint, may be very materially altered.

A mere screen examination is not sufficient, as often a fracture, which is perfectly obvious in the negative, is not seen, and cannot be seen, on screening. More than one view must be taken; the fallacies of a skiagram taken, say, antero-posteriorly, and not further investigated by a lateral view, are well known. The ideal radiographic examination is a double stereo, *i.e.* two stereoscopic views taken, one antero-posterior and the other lateral.

The percentage of so-called sprains that are in reality sprains complicated by fracture is much greater than is generally realized, and the consequence of overlooking the fracture may be disastrous.

Fractures or fracture dislocations of the carpal bones, to say nothing of the more obvious fractures through the lower inch of the radius, are often treated as simple sprains for a week or two, and it is only then perhaps, when the case is not improving, the pain is persistent, and there is no return of function, that the patient himself insists on an X-ray photograph, or seeks other advice.

Acute sprains of the small interphalangeal joints, arising from a fall, or such actions as fielding a ball at cricket, are often cases in which a small flake of the phalanx is fractured. There is no displacement, the joint is swollen and its outline obscured, and the fracture cannot be diagnosed except by a skiagram. In these injuries to the small joints of the finger or thumb, the whole prognosis turns on the fact of whether or not there is a fracture complicating the sprain. If there is no fracture, the joint condition clears up readily under almost any form of treatment—except prolonged rest. But if there is a small scale of bone detached and but little displaced, a not uncommon complication, the prognosis is more serious. The swelling and disability will persist for a long period, the length of time depending on the treatment adopted to some extent.

I advise gentle massage and ionization with sodium salicylate in this situation, with gentle movements of the joints such as can be voluntarily performed by the patient himself. Nothing in the nature of violent movement, the so-called passive movements, must be allowed.

The joint settles down as a rule in, say, from a month to six weeks, but I have seen several cases of this nature in which the fracture was unsuspected two months or more from the time of the accident. A case in point, of which the skiagram is reproduced, is perhaps worth recording.

The patient, Mrs. R., was sent to me in March, 1911, suffering from an injury to the left thumb. Her history was that she fell on the hand ten weeks before, and that she had had pain in the thumb, and also felt pain in the palm of the hand and radiating up the arm ever since. She had seen her doctor, who had bound up the thumb in a splint for fourteen days and painted the joint with iodine. The condition had not

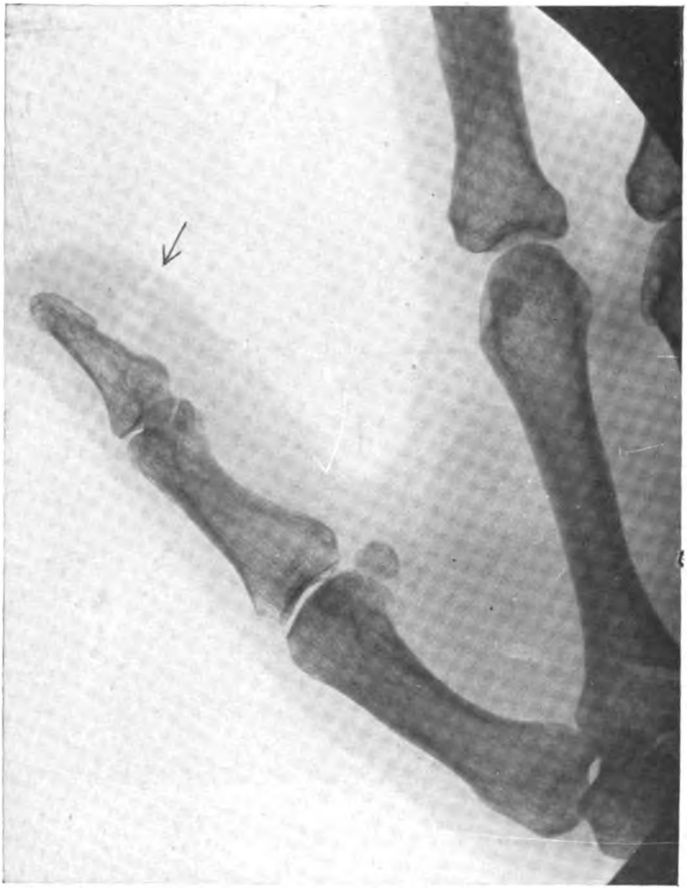

FIG. 328. FRACTURE OF THE BASE OF THE TERMINAL PHALANX OF THE THUMB —WITH PRACTICALLY NO DISPLACEMENT. The impossibility of making a certain diagnosis without the help of a skiagram is obvious.

improved; no skiagram had been taken; she had been told that she had 'sprained the thumb'.

When I saw here there was marked swelling of the interphalangeal joint of the thumb, which was painful, especially on pressure, and stiff, and she was herself unable to flex the terminal phalanx.

An X-ray examination revealed a tiny oblique fracture of the base of the terminal phalanx. Gentle massage for ten minutes night and morning was ordered, as ionization was impracticable in this case, and she was told to use the hand.

The disability was overcome in a few weeks, but the joint never became normal.

In fracture-sprains in this situation a guarded prognosis should be given, for these small joints do not become quite normal again in many cases. When, as in the case recorded above, the true nature of the injury is not recognized, and the lesion is regarded as trivial by both the doctor and the patient, it is sometimes difficult to make the latter understand that it is the original injury rather than the treatment which was adopted in the first case that is accountable for the continuance of the symptoms.

Arthritic changes, followed by thickening, are a common sequel to injuries to these small joints, more especially if vigorous methods are adopted to promote movement in the early stages.

Treatment. Wherever possible in acute sprains the treatment by Graduated Contraction is commenced from the outset, and the earlier the case comes under treatment the sooner will it recover. Active treatment is commenced usually twenty-four hours after the injury; it does not cause increased pain, but rather immediate relief. The contractions first produced should be small, and nothing like full contraction of the affected muscle should be attempted.

In a case of joint sprain, the muscles which normally move and control the joint are treated, and the joint itself is gently moved by their contractions. No pain is produced even by the joint movement, although the patient may be quite unable to produce that movement himself, voluntarily, on account of pain.

The strained muscle is damaged to an extent depending on the severity of the accident, and its tone is altered.

What is claimed is that restoration of normal tone, the essential factor to recovery, is brought about more quickly by this method than by any other.

This restoration is immediate but temporary—each succeeding treatment produces more lasting benefit.

The patient is of necessity conscious of this improvement, and commences to use the limb, and so by active exercise hastens his own cure.

And here let it be stated that rest has no part in the treatment of sprains after the first twenty-four hours, unless the pain is excessive. In looking through the notes, taken at the time, on my own cases, I find it has very seldom been necessary to tell the patient to refrain from using the limb. On the contrary, he has been encouraged to exercise gently the damaged joint. I am aware that this is contrary to the recognized teaching, but I have seen no bad results follow. In some cases the patients have been medical men, and I have had some difficulty in persuading them to use the limb at first, or bear any weight on an

FIG. 329. FRACTURE OF THE FIBULA WITHOUT DISPLACEMENT.

ankle-joint in the early stages. Once I have overcome this diffidence, there has been no further trouble.

I am always at considerable pains to re-educate these patients when they commence to walk, pointing out the necessity of taking short steps, bearing a due proportion of the weight on the injured limb, heel and toe walking, and so forth.

Light massage is advisable in addition in acute cases. This is the readiest method of reducing the swelling and overcoming the pain caused by the distension of the joint and surrounding structures. This massage can be undertaken without in any way interfering with the treatment by Graduated Contraction already recommended. Indeed, both are necessary, the one to restore tone to the muscles—the other to reduce the œdema. The necessary mobilization is carried out physiologically by the active contractions of the patient's muscles, therefore no passive movements need be given.

Pressure bandage. If there is much swelling, it is helpful to apply pressure by firm bandaging applied over many layers of cotton

FIG. 330. LATERAL VIEW OF SAME CASE. THE OBLIQUE FRACTURE OF THE FIBULA IS JUST VISIBLE IN THE SKIAGRAM. In many cases the fracture cannot be seen in this view, whilst it may still be obvious in the antero-posterior view.

wool for a few hours. This is only applicable to cases seen immediately after the accident, and is to be recommended during the first twenty-four hours.

The joint and neighbouring part of the limb are swathed in wool—a considerable thickness being applied, and pressure is obtained by applying a bandage tightly over this. The bandage should be applied firmly and evenly. Another layer of wool is wrapped round outside this bandage and a second bandage tightly wound round this.

At the end of a few hours the bandage should be removed. Its use is mainly in preventing further extravasation and in promoting absorption.

Strapping. The alternative line of treatment to electrical stimulation and massage consists in the use of adhesive plaster strapping; but in most cases I prefer to rely on the immediate restoration of normal tone in the muscles produced by the method described. In slight sprains this is all that is necessary, and the functional result is speedily obtained. Once restore tone in the muscle, and it will of itself support the injured joint. The treatment by strapping is most often called for in dealing with severe sprains of the ankle-joint, with rupture of one or other of the lateral ligaments. The strapping is applied so as to keep the damaged ligament relaxed, by holding the foot slightly inverted or everted as may be necessary, and so avoiding injury to the newly formed fibrous tissue. Crooking of the heel of the boot and increasing the thickness of the sole on the inner or outer side, as may be necessary, also prevent overstretching of the damaged part.

When the joint is supported by the plaster, the patient can as a rule walk with some degree of comfort, and he should be encouraged to do so, his early attempts being supervised and walking instruction given. Functional use, provided it does not cause fresh injury, is a speedy and effective stimulant to recovery.

In acute sprains the treatment advised is Graduated Contraction once a day for twenty minutes, with increasing amplitude of joint movements from day to day, together with gentle massage in the early stages to reduce the swelling, and so get rid of the pain. I do not strap up the joint in slight cases after or between treatments.

Sprains of the adductors. I have come across a large number of cases of sprained adductor longus which have been treated by strapping, and have gradually become so bad that, even with the strapping on, they cannot ride without pain or in any comfort. The strapping has simply acted as a stop, applied near the pelvic attachment, the common site of injury; it has enabled the muscle to act between its fixed point below, viz., attachment to the femur, and this temporary fixed point (the ring of strapping) above.

The actual muscle injury has joined up perhaps, but with intramuscular adhesions, formed from the organized lymph. This part of the muscle between the strapping and the pelvic attachment has not been exercised, and is toneless and painful as soon as it is called upon to act.

Moreover, the shortened adductor, between the strapping and the femoral attachment, is still liable to injury in jumping, &c., and should this shortened muscle get strained—as in practice it sometimes does—the patient is worse off than ever.

I have seldom known massage promote recovery in a true 'rider's strain'. In this condition the treatment here recommended can be advised with confidence and with every hope of success, even in long standing and stubborn cases, and no matter what other line has been adopted and failed previously. Treatment should be given daily in these cases, powerful contractions obtained and no bandage allowed. At the end of a week in an average case the patient is permitted to get on a horse and hack about quietly. This is an advantage, as it educates the recovering muscle to functionate and take part in the movement of adduction.

During the second week, exercises against resistance are added, and at the end of this period—*i.e.* a fortnight—the patient should be able to resume hunting.

The following account of the case of R. C. T., who consulted me on November 9th, 1911, gives a fair picture of what often happens in these cases.

The patient strained his adductor hunting in January, 1911. He was treated by strapping and later by massage and exercises, and hunted no more that season. He rode quiet horses during the summer without pain. On the first day's hunting in November, without any apparent cause, 'the leg went again'. He was unable to walk, and two days afterwards noticed a 'lump' over the affected muscle. He was told he could not hunt again that season, and that the prognosis as regards ultimate cure was bad. I saw him a fortnight after the second accident. There was a small hæmatoma near the pelvic attachment of the adductor longus, which muscle was lacking in tone and tender on pressure.

At the end of nine days' treatment he was allowed to hack, and on the 25th—*i.e.* after sixteen days in all—he hunted. He was 'seven hours in the saddle, had some good jumps and absolutely no pain at all'.

He reported at the end of December that he had been hunting regularly and had had no further pain or disability.

Sprains in the neighbourhood of the elbow. The sprains in the neighbourhood of the elbow are not quite so easy to deal with. In many the results are excellent, but some are particularly resistant to this as to all other forms of treatment which I have tried, and, judging from the length of history these patients often give, which others have tried as well.

Strapping or bandaging, massage and exercises, and in resistant cases 'the hot needle', all have their supporters. I would add the treatment by Graduated Contraction and also by ionization to the list, but a guarded statement should always be made as regards the immediate prognosis.

In my experience they all, or nearly all, get right in time. It is quite easy to cure the immediate condition, but it is no real cure if the symptoms return soon after resuming the form of exercise which originally gave rise to them.

In cases of sprain of the muscles about the elbow a skiagram should be taken to see whether there are any signs of arthritic change in the elbow or superior radio-ulnar articulations, as this condition often gives rise to a similar chain of symptoms.

These elbow-joint lesions—tennis elbow and so on—differ from ordinary sprains in being caused generally by the cumulative effect of certain active movements.

In many cases the history of onset is gradual, and this is a point to be taken into consideration when giving a prognosis. Those cases which prove to be resistant to treatment are often found to have given this history.

In many cases the results are quite satisfactory, active treatment of all muscles round the joint being undertaken. Any adhesions present are broken down by the muscles themselves, as they are made to contract strongly and independently of one another.

If there is any limitation of extension this should be forcibly reduced, under an anæsthetic if necessary. This is not always easy, as from the anatomical structure of this joint it cannot be forced into a position of hyper-extension.

In giving a prognosis in the case of a sprained muscle (other than the particular types of case already referred to)—*e.g.* biceps of the leg—it is necessary to give attention to the history of the accident.

In this case the lesion is a laceration of muscle fibres with some degree of rupture. This may be marked so that one can feel a definite sulcus, or may be apparently slight and nothing may be felt on examination.

But the point to which I attach importance is as to whether or no the injury was caused by overaction of the muscle or was due to external causes. In the latter case, too, there may often be an actual sulcus to be felt.

In my experience, a muscle injury, the result of overaction of the muscle, takes much longer to recover than does one due to external trauma.

The biceps is sometimes damaged by athletes, in, *e.g.* suddenly starting to sprint, and although an apparent cure can be obtained in a few days with loss of all pain and no limping or disability in walking, yet the injury will recur very readily if the muscle is again subjected to similar strain.

Strapping the muscle will not prevent this recurrence. Gradual exercises should be given, and no sudden strain be thrown on the muscle for a period of from three weeks to a month.

On the other hand, if the disability is caused by, say, a kick, there is not the same liability to recurrence, and a much shorter convalescence is recommended. The site of previous rupture of the muscle fibres may be evident for some years after the injury, and may not disappear at all.

The ruptured fibres join up by fibrous tissue, and the whole muscle will functionate perfectly well, and suture, by operation, is seldom called for.

I think a point in favour of treating these muscle injuries by the Graduated Contraction method is that every fibre is made to contract. In this way, intra-muscular adhesions between the various muscle bundles may be prevented, or should they be formed are stretched and broken down, and contractures in the neighbourhood of the scar in the muscle when union is completed are prevented.

There is in addition a psychic effect, which is produced in the mind of the patient when he sees his own joint moved by the contractions of his own muscles *without pain.* This is undoubtedly of value, and may considerably shorten the convalescence.

CHAPTER IV

THE SEQUELÆ OF ACUTE SPRAINS—CHRONIC SPRAINS

A SIMPLE sprain which is neglected or inefficiently treated is likely to be complicated by further symptoms, and the disability is termed a chronic sprain.

The most common sequelæ of acute sprains are:—

I. Persistent pain,
II. Adhesions,
III. Atrophy,
IV. Recurrent synovitis,

and they could in the main be obviated if these injuries were correctly diagnosed and treated with the care and attention which they demand.

A sprain treated on the old-fashioned lines of rest, splintage, ice-bags, and evaporating lotions will be very often followed by one or more of these complications.

The treatment of these conditions supplies the main field of work for the bonesetter at the present time, and will continue to do so until the medical profession, as a whole, will devote to the treatment of injuries the same care as is given to other branches of surgery.

Until medical men recognize that in the treatment of these cases there is something to be learnt apart from the ordinary teaching of the text-books, cases will still drift to the bonesetters, who will continue to gain much credit for their successes, and lose but little by their failures. That bonesetters do harm in some cases is self-evident and universally agreed—that they do good in some is equally certain.

To say that the bonesetter's methods are well known is not enough. Has the medical profession got the same or improved methods at its disposal, and are these methods put into practice?

These methods are quite well known and at the disposal of every qualified man. They consist in the main in breaking down adhesions by manipulation, and the most successful cases are those in which the adhesions are peri-articular.

Are these methods put into practice? Judging from the length of history often obtained from this type of patient, I should say that in many instances they are not practised. What often happens is that the stiff and painful joint is wrenched under gas, but that it stiffens up again and the patient's condition is not improved in the slightest. The patient is told to rest, and the treatment by forcible manipulation is condemned.

Or again, in some cases the wrenching is repeated at frequent intervals, the joint being forcibly moved daily. The range of movement gets less and less, the pain persists and becomes more acute, and again the line of treatment is condemned.

What has really happened in these cases is that the wrenching has not been carried sufficiently far. For example, if it is considered desirable to break down adhesions round a knee-joint, it is not enough to get full flexion and full extension. Full rotation with flexion, and with flexion in all its stages, must be made sure of. If the knee is simply bent forcibly, small adhesive bands are left unbroken, and probably stretched by the manipulation. These will necessarily become inflamed and give rise to pain. Had the wrenching been thorough, they would have been completely divided and caused no more trouble.

As pointed out long ago by Wharton Hood in his description of the methods of the celebrated bonesetter, Hutton, it is this rotation, so often omitted, which is regarded by the bonesetter fraternity as so important. Wharton Hood writes of Hutton as saying, 'Pulling is of little use, the twist is the thing'.

Another point to be remembered in breaking down the adhesions in stiff joints is that one complete movement in every direction is all that is necessary.

Wharton Hood describes the method of applying the force. The most tender point about the joint in movement in any given direction being found, this point is anchored with the thumb. The other hand grasps the limb below the joint, and rotates it, so as to put the opposing muscles at a disadvantage. The limb is then forcibly flexed or extended to the full range of movement, and at the same time rotated. As pointed out above, rotation must never be omitted.

Choice of anæsthetic. The choice of anæsthetic is of importance when the breaking down of adhesions is undertaken. Nitrous oxide gas alone is unsatisfactory, because in order that the manipulations may be carried out satisfactorily two things are necessary:—

(i) **Sufficient time,** so that the operator need not be hurried, but can methodically carry out the various manipulations.

(ii) **Muscular relaxation.** Although there may be sufficient time allowed with gas, there is usually spasm of the muscles.

Used in combination with oxygen, by a skilled anæsthetist, nitrous oxide suffices for many cases, but in dealing with the shoulder-joint or the hip-joint a general anæsthetic, either chloroform or ether, or a combination of the two, is to be preferred.

Diagnosis. It is essential before undertaking the treatment of such a case to have a very clear idea of what has happened, and, as far as possible, of the extent of the damage, if anything like an accurate prognosis with regard to the length and result of treatment is to be given.

An X-ray examination should be made in every case, skiagrams being taken, as a screen examination is insufficient. The examination of the joint must include a comparison with that of the opposite side, as it is only by this means that slight limitation of movement in any one direction can be noted, and moreover, the range of movement allowed in a normal joint varies in different individuals.

A very slight limitation of a movement in the ankle-joint gives rise to pain on walking, and until the limitation of movement is overcome the pain recurs. No treatment short of forcible breaking down of the adhesion will cure such a case. This simple procedure is followed by complete cure. Often these ailments are diagnosed vaguely as ' rheumatism ', and are given various treatments at spas and hydros.

A case in point which serves as an instance is that of a girl I saw in 1913. She gave a history of a bad sprain three years before, through a fall, skating. She was laid up for six weeks at the time and was told she had torn the ligaments of her left ankle. X-ray examination immediately after the accident did not reveal a fracture. At the end of a year, during the whole of which time she had been unable to walk any distance or take part in games, she again damaged the ankle. She was laid up for a further period of some months, and was then given special boots and told to walk and exercise the foot. She was unable to do this to any extent on account of the pain produced by the exercise, and when I saw her three years after the original accident she said she could only walk about a mile, and could not play golf or tennis. After walking she always had pain in the ankle, which ached and sometimes kept her awake at night. Two years before I saw her the ailment had been diagnosed as chronic neuritis, but had failed to respond to any treatment advised, and a year later she had taken other advice. This time ionization with iodine, massage and electrical treatment were ordered, but produced no good result.

There was no evidence of tubercle, the joint movements, which were nearly complete, were painless, and an X-ray examination showed a normal ankle-joint.

On comparing the movements of the two ankles, however, dorsiflexion on the left—the affected side—was not quite so full as on the right.

The adhesions were broken down without difficulty, and the muscles, which were weak from continued disuse, were treated for a short time by Graduated Contraction and exercises.

One month later the patient was playing tennis and getting about normally, which she had not done for three years. I heard from her a year later that the ankle had given no more trouble.

This case presented no particular difficulty, but I have described it in some detail because it is just the type of case which a bonesetter would have cured. The only point was to recognize the slight limitation of movement, and having recognized it to realize that this was accounting for the pain and disability. The treatment was easy, and yet this girl had been more or less incapacitated for three years.

Diagnosis of intra-articular lesions. When there is a lesion in the joint there is usually pain on movement in every direction. When there is complete freedom of movement in one or more directions, the lesion is probably peri-articular, and complete breaking down of the adhesions will be successful.

Limitation of movement in all and not merely in one direction is evidence of arthritis, and forcible manipulation under an anæsthetic is likely to fail in cases in which the joint surfaces are involved.

Treatment by gradual correction. If the joint itself is involved, the method of correction by gradual splinting, with extension as advocated by Robert Jones, should be attempted, as rough handling will be followed by inflammation and still further limitation of movement, if the arthritic changes are active.

The method of gradual correction of deformity for limitation of flexion at the elbow, by the collar and cuff (Owen Thomas), will serve as an example. A leather collar encircles the neck, and a second one the wrist, and the two are joined by a strap or bandage, which is applied with as much tension as is allowed by the patient. The continuous pull on the joint will increase the angle of flexion and the bandage will become loose. The bandage is tightened from time to time until the flexion allows the hand to be brought to the neck. The collar and cuff are now removed and the forearm is bandaged to the arm, in flexion.

When full flexion has been gained, the elbow is gradually allowed to extend again. A few degrees of flexion are allowed, the movement being limited by the collar and cuff, which is reapplied. The patient must control the movement, and retain power of flexion, before the bandage is loosened and more extension allowed. When he is enabled to flex the arm voluntarily from extension to about a right angle the apparatus is removed. The force of gravity and the use of the arm gradually increase this extension.

A screw extension apparatus for overcoming flexion deformity is illustrated, working on a similar plan to the Turner splint for the knee.

Further, the method for the gradual correction of deformity by the application of gradual force by continuous splintage is recommended:

(1) In cases of subacute arthritis of long standing, in which movement is markedly restricted.

(2) In cases of deformity resulting from contracture of *scar tissue*, the result of either wounds or burns, limiting joint movement.

(3) In treating Volkmann's ischæmic paralysis or contractures fol-

FIG. 331. STAGE I. GRADUAL CORRECTION OF DEFORMITY IN CASE OF FLEXED ELBOW-JOINT. This joint had been flexed for six months by contracted scar tissue and fibrosis of the muscles.

lowing peripheral nerve injuries. In all these cases the gradual stretching will yield infinitely better results than will be got by attempts at forcible breaking down of the obstruction.

Satisfactory results may be obtained in cases in which the disability is due to post-traumatic osteo-arthritis by forcible manipulation under an anæsthetic followed immediately by massage and movements. The disease in these cases is inactive, and muscular wasting with a stiff joint the main symptom.

In these cases the manipulations may have to be repeated more than once. Gentle massage should be commenced before the patient has recovered from the anæsthetic and repeated two or three times during the first twenty-four hours. This massage will relieve the pain and allow the patient to move the limb.

Any markedly wasted muscles should be treated from the first,

FIG. 332. STAGE II. THE SAME TEN DAYS LATER. The patient, by turning the screw, having gradually straightened the arm. At this stage the splint is removed and a straight splint applied, to complete the correction.

Graduated Contraction being replaced by graduated exercises as they recover.

Pain and adhesions go together in chronic sprains, the pain being kept up by slight irritation of the fibrous bands in movement.

Muscular wasting. The treatment has already been fully discussed. In this place I would only like to point out how often muscle wasting is the one really important symptom.

Impairment of function at the shoulder-joint and consequent disability as a result of wasting of the deltoid is a common sequel to the injury of this joint. The wasting is intense in some cases, and, moreover, may be localized to some particular set of fibres—most often the posterior fibres. Here the treatment should be conducted on the lines already laid down.

What can be done for some of these chronic joint cases of long standing is well shown in the following account of the case of an old doctor (T.) I saw on May 8th, 1911. The history was as follows: He had damaged his right knee in January, 1910, and this was followed by an attack of 'rheumatism' in the joint, which swelled up. He was in bed on and off for two months, and then used crutches. The knee got stiff, and in November, 1910, it was forcibly manipulated, but this did not increase the range of movement. He was still using the crutches when he came to me, and had been doing so for seventeen months.

When I saw him there was marked wasting of quadriceps, especially of the vastus internus, fluid in the joint, and some lateral movement. Extension was complete, but flexion only possible to just a right angle, and there was tenderness along the joint line on the inner side. X-ray examination showed a normal condition of bone, and there were no osteophytes.

He was treated by Graduated Contraction of the quadriceps and massage. The progress of the case is interesting.

After a fortnight's treatment he was able to bear some weight on the leg, and walk with the aid of sticks. There was rather more fluid in the joint, but no change was made in the treatment, nor was the leg rested because of this. Ten days later the fluid had practically gone, and he was able to walk a short distance without his sticks. After nine weeks' treatment he was able to walk quite well without sticks or supports of any kind, and the muscular development was excellent.

He reported a month later that the knee was as good as the other, and that he had walked a mile or two without inconvenience.

The above case is recorded to show that with very extreme wasting a satisfactory result can be obtained. The measurements in this case were:—

Circumference of Thigh.	May 8.	May 29.	July 14.
3″ above upper border of patella........	14″	14½″	15″
8″ above upper border of patella........	17¼″	18″	19″

In cases of muscle wasting, any tendency to stretching and elongation of the muscle must be prevented.

This is especially important in cases of peripheral injury, when the wasting is profound.

By suitable splintage the muscle can be kept in such a position that there is no direct strain on its weakened fibres, nor is the weight of the limb allowed to drag on them. Also the pull of the opposing healthy muscles is counteracted.

For example, when there is weakness of the anterior tibial group and tendency to foot drop, the foot should be kept by a splint at a right angle, or less than a right angle to the leg; the wrist and hand are kept dorsiflexed if there is marked wasting of the extensors, as in lead neuritis, or paralysis following injury to the musculo-spiral nerve.

The use of splints in no way interferes with the treatment of the muscles by massage and electrical stimulation.

It is in cases of marked wasting, or loss of function due to the muscular weakness, that this method of putting up the limb with the muscles fully relaxed is necessary.

Recurrent synovitis. This condition and its treatment will be dealt with in considering the treatment of the knee-joint, in which situation it most commonly occurs. Its treatment in other joints is on similar lines.

Sprains of the knee-joint and internal derangement. What has been said of sprains both acute and chronic of other joints applies equally to the knee-joint, and this fact must be emphasized, because there is a tendency to regard all injuries to the knee-joint as displacement of a semi-lunar cartilage.

The fact that an injury to the knee-joint is in many cases a simple sprain, which is liable to become chronic and be complicated by muscular wasting and the formation of adhesions, must not be overlooked. The knee-joint, like the shoulder, depends very largely for its strength and function on the muscles and more particularly on the quadriceps extensor. The crucial ligaments and the strong posterior ligament are injured but rarely, and the type of case most often met with is a weak knee, the result of quadriceps insufficiency.

The condition of severely damaged internal lateral ligament is observed most often when examining a knee-joint after an operation for the removal of a semi-lunar cartilage. Marked lateral mobility of the joint, with pain on pressure, at both the femoral and tibial attachments of the ligament, together with the history of the case, suffice for diagnosis.

With quadriceps wasting, and the strain thrown on the joint from this cause, the ligament is likely to be stretched, but this will give rise to no further symptoms if the primary cause—quadriceps insufficiency—is overcome.

Now there is a great tendency to regard any severe sprain accompanied by pain and synovitis as an injury to one or other of the semi-

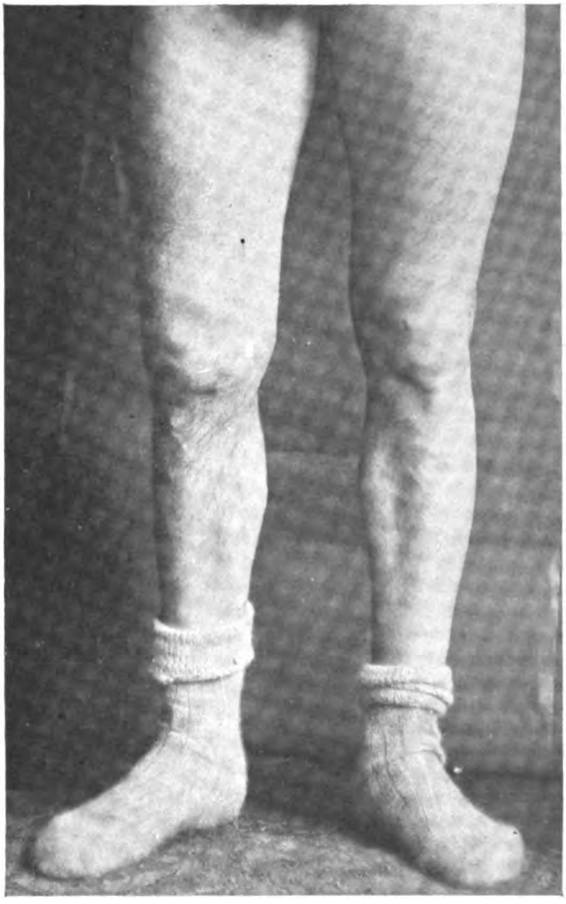

FIG. 333. CHRONIC SYNOVITIS OF RIGHT KNEE, WITH MUCH WASTING OF THE QUADRICEPS. The wasting in these cases is masked by the swelling of the joint.

lunar cartilages, and operations for their excision are advised all too frequently.

The tremendously important *rôle* played by the quadriceps is not generally understood. Any severe injury to the knee is followed by wasting of this muscle group, and more particularly of one individual muscle—the vastus internus. This wasting is masked to some extent if the joint is distended with fluid, but it is always there. Perhaps of even more importance is the extraordinary rapidity with which tone is lost in the quadriceps as the result of injury, thereby robbing the joint of what is normally its most powerful support, and exposing it to further risk of damage on slight provocation. For if the bracing effect of the quadriceps on the joint be lost, lateral movement, with its attendant dangers of nipping of synovial membrane and pinching of cartilage, is brought about by any slight strain on the limb.

When the quadriceps is wasted, repeated attacks of synovitis are common, owing to some slight injury to the synovial membrane in eccentric movements of the joint, which is insufficiently supported and has a tendency to lateral mobility—*e.g.* when exposed to such trifling injury as walking over rough ground.

If the membrane is nipped, there is acute and sudden pain; the patient may fall, and some hour or two later the joint will become distended with fluid, and there will be pain along the joint line on the inner side.

Rest for twenty-four hours, a compression bandage, gentle massage for the pain, and immediate treatment of the muscles by Graduated Contraction are indicated.

I always advise in addition ionization with a two per cent. solution of sodium salicylate if the amount of fluid is at all excessive. This can be carried out three times during the first week, and after that twice a week. To be of service, long sittings (forty-five minutes) and big currents are essential—60–90 milliamperes will be borne with correct technique. Short daily sittings with small currents are useless, and unless the ionization can be properly carried out it had better be omitted. The patient walks about a little after the first twenty-four hours, and is not kept at rest on account of the fluid, which gradually becomes absorbed with movement of the knee and returning strength of the muscles. Any overstrain will cause the joint to fill up again, but I do not often find it necessary to keep the patient at rest on account of this. As a rule, contractions of the muscles helped by ionization suffice.

It must be borne in mind that I am dealing here with the common type of case, in which there is no intra-articular lesion.

The presence of a fractured cartilage, a loose body, or sometimes a well marked, thickened synovial fringe, all give rise to fluid, and no treatment of muscles will prevent a recurring synovitis.

I do not advise a bandage during convalescence, but if one is deemed necessary, it should not extend above the limits of the joint. Firm pressure over the lower part of the thigh muscles is certain to induce muscular atrophy, and in consequence a recurrence of all symptoms on the slightest provocation.

If the quadriceps is so wasted that the patient is totally unable to bear his weight on the limb, or rather to maintain extension at the joint, as in very severe cases, the walking caliper splint will obviate the difficulty. The patient can get about, there is no pressure on the thigh muscles, which are at rest, and treatment of these muscles can be carried on until such time as they recover sufficiently to enable him to dispense with the caliper. He can, as soon as he is able, materially hasten recovery by practising tightening and relaxing the quadriceps, standing in the splint.

If support is necessary for the joint at this stage, the knee cage recommended by Robert Jones should be used. Any form of elastic knee-cap is bad, for if it is sufficiently tightly applied to be an actual support, it will impede the circulation and produce further atrophy, whilst if it is loose and comfortable it ceases to be any support.

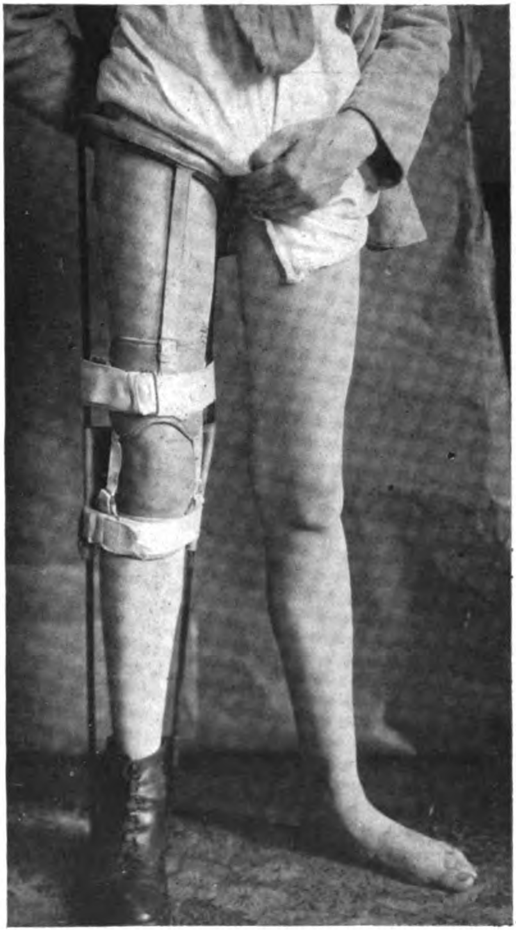

Fig. 334. Caliper Splint Applied—Front View. The leather pad above the patella is unnecessarily large in this case, and would tend to produce atrophy of the vastus internus.

Now the more usually adopted method of treatment in these cases is rest until all fluid is absorbed, probably with the knee and lower part of the thigh firmly bandaged, and when the fluid is absorbed, the patient is ordered massage and some form of exercise.

A back splint, bandaged on for walking, still further hampers circulation.

The result of this treatment is shown by the number of cases of recurrent synovitis of knee that are met with. In these cases, in addition to the atrophy there is often slight limitation of movement.

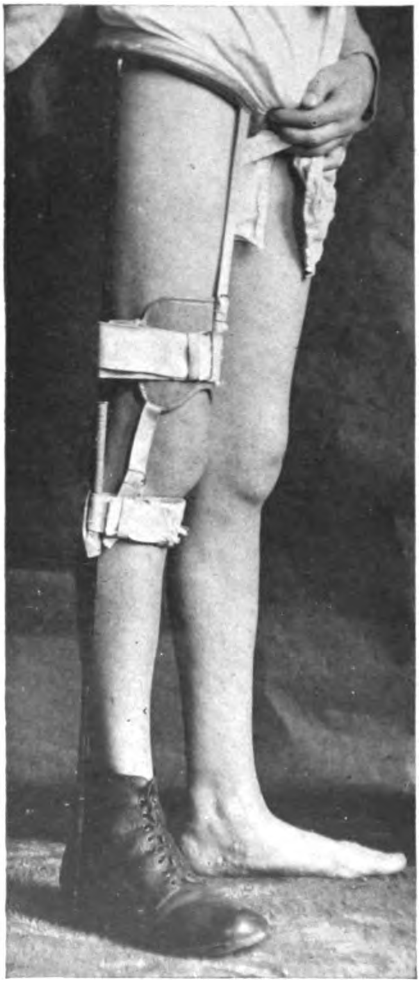

FIG. 335. SAME. SIDE VIEW—SHOWING ATTACHMENT OF THE IRON TO THE HEEL OF THE BOOT.

It is, I think, in cases treated on these lines that adhesions are particularly liable to form. The limitation of ordinary movement may be very slight, but the knee 'feels weak', and there is pain on the inner side in walking on uneven ground and often complained of in going up or coming down stairs.

These adhesions can be broken down by full movement, including rotation of the leg on the thigh during all degrees of flexion. This should be followed by exercises for the wasted muscles, any slight amount of fluid being disregarded and the patient encouraged to walk or use the limb.

These adhesions are often quite small, and are formed from organizing blood clot in the neighbourhood of the joint line, perhaps from some slight tear of the coronary ligament.

I think that in a consideration of these minor adhesions round the knee is to be found the explanation of what is undoubtedly a fact, namely, that the bonesetter by his manipulation sometimes completely cures this type of case. Moreover, it is often after the qualified man has failed, and very likely operation has been advised, that the bonesetter's services are called for.

The whole question has not received the attention it deserves and exploratory operation is often advised unnecessarily.

There is a condition of the knee sometimes met with, which must be carefully distinguished from a displaced cartilage, in which the patient complains that, on sudden twisting, the knee gives way, and yet on examination the quadriceps is found well developed.

On inquiring into the previous history of these cases, the disability is generally found to have originated in some accident to the knee-joint, after which the patient is laid up with fluid in the joint for a time. Subsequently, at varying intervals, he complains that the knee 'gave way' or 'went out', which he considers to be caused by some slight twist. Following this the joint generally swells slightly and he is incapacitated for a few days. Careful inquiry into details will usually elicit the fact that he does not fall, and that there is no history of locking.

On examination there may be pain on pressure over the joint line on the inner side, but this is not more marked at any one point than at any other.

No special tenderness on pressure is noted over the anterior attachment of the cartilage or over the attachments of the internal lateral ligament.

The quadriceps is well developed, and there is no wasting or loss of tone.

Full movement is allowed in both flexion and extension, but rotation in full flexion causes pain, and is slightly limited.

The condition is due to adhesions, the result of tearing of tissues in the original injury. These adhesions are not pulled on in ordinary joint movements, and only give rise to symptoms in certain movements, in this case the sudden twist.

Forcible manipulation under an anæsthetic is the treatment necessary.

The joint must be fully flexed and rotated in each direction, and then fully extended.

No special after-treatment of the muscles is called for, as they are already well developed, and the patient is told to use the leg and get about normally.

Intra-articular lesions. The consideration of cases which are curable by non-operative measures has been gone into at some length, and much is claimed for the results of treatment other than by operation.

But when operation is indicated, it should be most strongly advised, as the results, given appropriate after-treatment, are so satisfactory.

Moreover, if no operation is performed, the patient is perforce obliged to wear a large and cumbersome apparatus to prevent rotation at the knee-joint; and, further, even this will not absolutely prevent recurrence. Each recurrence is followed by synovitis and wasting, and repeated injury predisposes to arthritic changes in the joint.

The injury is one usually occurring in adults in the prime of life, so that operation is seldom contra-indicated by the age or general health of the patient.

Operation is not indicated in a primary lesion, as with treatment many of these displacements do not recur, but if there is recurrence, *with the muscles in good condition,* the sooner the offending cartilage is removed the better for the patient.

The site of the pain, or rather tenderness on pressure, usually just over the anterior part of the cartilage, coupled with a history of locking, and especially this history, are the main points of diagnostic value—always having due regard to the condition of the quadriceps.

As has been pointed out with quadriceps insufficiency the symptoms may be very similar and yet the condition is totally distinct.

A single recurrence with weak muscles should be treated on the lines already laid down—that is, the function of the quadriceps should be restored. Once the knee shows a tendency to recurrence of 'internal derangement' with the muscles normal it must be explored.

There is just one further point to insist on in this connection—viz., that operation does not cure the patient, but rather overcomes the mechanical obstruction heretofore preventing the cure. It removes the disability, and appropriate after-treatment will be crowned with success. With inadequate after-treatment the result will be failure. The knee continues to swell up, the pain on walking is not diminished, and the feeling of weakness and insecurity persists.

After-treatment should be on the lines laid down for redevelopment of the quadriceps, and this should be commenced gently, as soon as the wound has healed.

Massage is of little help in this connection, and cases are common in which months have elapsed between the time of operation and ultimate recovery. If treatment as advised above be adopted, the patient can walk practically as soon as the wound is healed.

Many surgeons like to keep a firm bandage on the knee for some time after operation. So long as its limits are confined to the joint, it will do little in the way of producing atrophy, and gives the patient a sense of security. No bandage should be allowed which tightly constricts the lower part of the thigh. There is always some wasting following the operation—more than could be accounted for from simple disuse of the limb, and this wasting must be kept within bounds.

CHAPTER V

THE AFTER-TREATMENT OF PERIPHERAL NERVE INJURIES

THE after-treatment of peripheral nerve injuries is of great importance at the present time, when nerve lesions the result of gun-shot wounds are so common. This after-treatment is mainly concerned with the condition of the muscles and joints. A consideration of the diagnosis and surgical interference is not within the scope of this chapter, but I propose to deal with the after-treatment in some detail.

The after-treatment of peripheral nerve injuries may be considered under two headings:—

1. **Postural.** Which aims at preventing (or if necessary correcting) deformity, and also preventing the over-stretching of the paralysed muscles either by gravity or by overaction of their unparalysed opponents.

2. **Nutrition.** Both are important and the one is the complement of the other. It is by attention to the muscles, joints, and tendons that the desired functional result is mainly brought about, granting that the original lesion of the nerve has been satisfactorily dealt with.

In the case of a divided nerve, treated by operation and sutured or freed from scar tissue, the postural treatment commences from the time of the operation, and the treatment by physico-therapeutical methods, which aim at maintaining and improving the nutrition, should commence as soon as the operation wound is healed.

Treatment must be persevered with until such time as recovery takes place, and the patient regains functional use of the limb. This time varies, and no hard-and-fast rule can be laid down. It may be anything from nine months to two years, and for the whole of this period treatment is necessary. The treatment of a divided nerve only commences when the nerve is sutured, but the treatment of the paralysis resulting from this nerve lesion may commence as soon as the case comes under observation. The muscles must be maintained in as good condition as possible, and the joints kept free, in order that they may respond when the nerve recovers and is able to conduct stimuli. Recovery in the nerve may be completely discounted if there is no muscle substance remaining, and if degeneration has advanced to such a stage that the muscle substance is replaced by fibrous tissue.

Again, if the postural treatment has been omitted, or imperfectly carried out, and contracture due to the unopposed and healthy muscles has been allowed to take place, the nerve recovery is discounted—for treatment is of little avail which leaves the patient with a non-paralysed but perfectly useless limb.

I should here like to call attention to the fact that, although I am referring to post-operative treatment, most of the following remarks hold good equally for pre-operative treatment in addition.

A great deal may be done to help the nutrition of the limb before the divided nerve is sutured. No attempt is made to suture a divided nerve in the presence of sepsis—as healing without suppuration is an essential to successful nerve suture. But very often in gun-shot wounds some long time may elapse, during which efforts are made to combat sepsis, and perhaps promote union in a fracture, before the wounds heal. If such a wound is complicated by the division of a nerve, attention must be paid to the treatment both as regards posture and nutrition, although time must elapse before exploration and suture are safe procedures.

The care and thoroughness with which this pre-operative treatment is carried out will have a marked effect on the time and possibly on the completeness of the recovery.

It may be necessary, at the time of operation, to modify the treatment by posture, in order that there may be as little tension as possible on the sutured nerve. Often in gun-shot wounds there is some difficulty in approximating the cut ends of the nerve owing to two or three inches or more being totally destroyed and replaced by scar tissue, and every possible means is taken to relax the tension. It is obvious that the musculo-spiral nerve, for example, will be relaxed if the elbow is flexed, and that the median and ulnar will be relaxed with full palmar flexion of the wrist and hand. These and similar postural devices are employed for the first two or three weeks after nerve suture, and it is very important that these positions shall be in no way interfered with.

(1) **Treatment by posture.** The importance of posture cannot be over-estimated. It is in fact all-essential to recovery. After suture of a divided nerve the limb must be put up in such a position that there is no strain or tension on the paralysed muscles. Robert Jones, in 'Notes on Infantile Paralysis', reports the case of a patient who for eighteen years had not used the wrist because of complete wrist-drop following infantile paralysis. Recovery had taken place in the nerve, but the over-stretched extensors could not functionate. In two years, by postural treatment—the wrist being kept dorsiflexed in a cock-up splint—complete recovery took place. This was in 1885. I am referring to this case here to show that the postural treatment is not new, although it is

sometimes overlooked. The case quoted is one of infantile paralysis and not a peripheral nerve lesion, but the same point holds good for both conditions.

The postural treatment must be continuous, night and day, until the function is restored, and the paralysed muscles should never be allowed to be overstretched.

The treatment by massage and electricity must not interfere with this postural treatment, and even if the splints are taken off, the paralysed muscles must be kept relaxed during the time that the limb is undergoing massage or electrical treatment, as at all other times.

In a few cases too long continued use of a splint may result in stiffness of the joints, so that the patient complains that he has now lost all power of movement, *e.g.* in a hand which previously had some slight voluntary power.

For example, if with a lesion of the musculo-spiral nerve the hand is held in extreme dorsiflexion, and this position is maintained for too long by the continued use of the splint, he may be unable to flex the wrist.

In practice, if the limb is treated on the lines suggested the slight movement of the joint produced by the contractions of the muscles will prevent this occurrence. Again, the position of extreme dorsiflexion is unnecessary and a moderate degree all that is required.

Brachial plexus. For lesions of the upper part of the brachial plexus, usually affecting the fifth and sixth cervical nerves, with paralysis of the deltoid and biceps, the arm should be fixed at about a right angle to the side on an abduction splint, with the elbow flexed. This splint may be made of metal, or of plaster of Paris. It is important to make it as comfortable as possible, as it may have to be worn for a considerable period. A well-padded strap, passing from the axilla on the affected side round the neck on the sound side, is necessary to hold this splint in position, and the splint should fit well into the chest wall, curving outward at its lowest part, in order to take purchase from the iliac crest.

The patients tolerate the apparatus very well in practice, and when it is removed for washing purposes the arm must be held in position and not allowed to fall to the side.

A less irksome, but less efficient, method of dealing with this condition is to support the weight of the arm in a sling, approximating as far as possible the elbow and acromion, a similar method to that employed for supporting the arm after a dislocation of the acromio-clavicular joint. However well adjusted, this sling only prevents over-stretching of the deltoid by supporting the weight of the arm, and does not approximate the origin and insertion of the muscle, and so hold it in a position of true relaxation.

Musculo-cutaneous nerve. For lesions of the musculo-cutaneous nerve, with paralysis of the biceps, the elbow should be kept flexed by slinging the wrist to a collar round the neck—the collar and cuff method

FIG. 336. ABDUCTION SPLINT—FRONT VIEW. The splint should fit more nearly to the axilla.

—or more complete relaxation can be obtained by fixing the forearm to the arm, with the elbow in extreme flexion, with a bandage and adhesive plaster strapping.

Ulnar nerve. For an ulnar lesion the clawing of the hand due to paralysis of the interossei is the deformity to be guarded against. To counteract this a small metal or plaster splint should be moulded to fit the hand, and arranged so as to produce a slight degree of flexion at the metacarpo-phalangeal joints, and to prevent flexion at the interphalangeal joints.

Usually the little and ring fingers alone require splintage, and signs

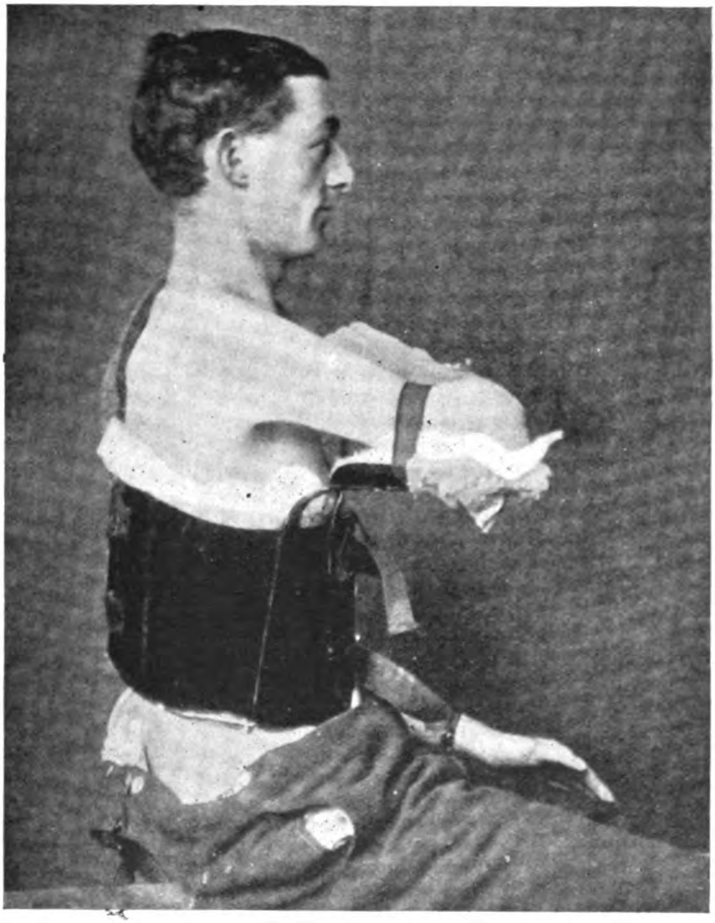

FIG. 337. ABDUCTION SPLINT—SIDE VIEW.

of commencement of this deformity must be watched for and its development guarded against.

Median nerve. Special postural treatment is seldom needed in cases of median nerve injury. The main deformity in a lesion of the median is extension of the first finger and thumb, and particularly of the first finger. Applying the same principles in this case as are employed in the others, the first finger should be kept flexed both at the metacarpo-phalangeal and at the interphalangeal joints.

In cases in which there is a median and ulnar paralysis combined—and this is often seen in practice—it may be well to apply splints, obviating the deformity from the commencement. They may be worn at night and left off during the day. The movements of the hand and the automassage so produced are beneficial, and the first signs of deformity can be watched for and guarded against by applying splints as soon as signs of their appearance are noted.

Musculo-spiral and posterior interosseus nerves. In injuries of the musculo-spiral and posterior interosseus nerves the hand must be kept in the dorsiflexed position by some form of 'cock-up' splint. In the early stage this splint should also support the fingers—the long cock-up.

The hand piece of the splint should be flexed slightly at the level of the metacarpo-phalangeal joints, as hyper-extension of these joints may otherwise occur. There is a tendency for the hand to slip upwards off the splint, and if this occurs the point at which the pressure producing dorsiflexion is taken will be the tips of the fingers, and extension will be more marked at the metacarpo-phalangeal joints than at the wrist-joint. In adjusting the splint, which is applied to the palmar surface, the wrist should first of all be firmly bandaged to the convex part where the hand and arm pieces meet, and if this is done the hand will be maintained in the correct position. The best splint is one made of plaster of Paris and moulded to support the hand so that all the joints of the hand and fingers are kept in the required position.

Either form, metal or plaster, should have a thumb piece, as otherwise flexion deformity of the interphalangeal joint of the thumb may occur, due to the unopposed action of the flexor longus pollicis, which is supplied by the median nerve.

With commencing recovery a short splint terminating in the palm and allowing free movement of the fingers should be used. With this splint a glove, with elastic bands reinforcing the extensor tendons, is to be recommended. These elastic bands should pass over a wooden bridge—like a violin bridge—on the dorsum of the wrist, as otherwise they may slip off the extensor surface, and into the clefts between the fingers. If they do slip in this way they will act as flexors and produce the very reverse effect to that for which they are intended. The tension of this elastic is such that it will allow the fingers to be moved by the patient voluntarily contracting his flexor muscles, but keeps the fingers extended—that is, the extensors relaxed—when the hand is not being used.

The splints should be dispensed with when voluntary power of dorsiflexion is recovered and not before. If they are left off too early the case will relapse again.

External popliteal nerve. In the case of the lower limb, treatment by posture is most often called for in lesions of the external popli-

FIG. 338. APPARATUS FOR USE IN CASES OF FOOT-DROP—DUE TO PARALYSIS OF THE EXTERNAL POPLITEAL NERVE.

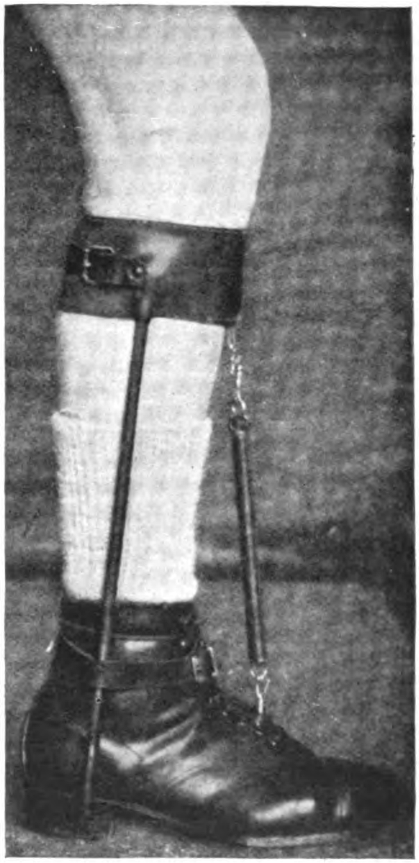

FIG. 339. SPRING FOR DEALING WITH FOOT-DROP. Note the leather collar is too loose and does not take purchase from the calf of the leg.

teal nerve, with paralysis of the extensors and consequent foot-drop.

At night these patients should wear a splint holding the foot in slight dorsiflexion.

Either a club-foot shoe or a celluloid or plaster splint will suffice. A light plaster of Paris splint may be easily and cheaply made, and will answer the purpose quite well.

For prevention of foot-drop during the day some form of toe elevator must be attached to the boot. There are many patterns in use, but the most satisfactory is the one figured in the illustration. It consists of a light outside iron from the heel of the boot, which serves as a support for a leather-covered iron collar encircling the leg quite loosely just below the knee. To this collar is fixed a spiral metal spring, which passes down under the trousers and is attached to an eyelet in the boot.

A felt gaiter may be used as the upper point for attachment of the spring, but it tends to be pulled down and to press on the dorsum of the foot, causing œdema. A similar objection holds good in the use of a leather garter, or, in fact, any form of apparatus which takes its purchase from the calf of the leg or the knee, and to overcome this the garter or collar should be suspended from the pelvis.

Internal popliteal nerve. With paralysis of the posterior tibial group the foot must be held in the equinus position to obviate contraction of the extensors and the production of talipes calcaneus.

(2) **Nutrition.** The measures to be employed for the improvement of the nutrition of the paralysed limb are directed primarily to restoring the condition of the muscles, and are similar to those described in the treatment of other forms of atrophy. Attention must be called, however, to the particular treatment which should be carried out during the various stages of recovery which take place as the nerve regenerates.

These may be considered under the following headings:—

1. Electrical stimulation.
2. Massage.
3. Heat.
4. Exercises.

Each of these will be dealt with quite briefly in turn, but they must be regarded as supplementary to each other and be combined in the treatment of any actual case.

Ordinarily speaking, treatment commences as soon as the wound has healed, and should be carried out daily in the early stages, and more frequently as recovery advances.

I. **Treatment by electrical stimulation.** Here we are dealing with electricity simply as a stimulus, to provoke muscular contraction.

Galvanism. In the early stages the muscle will only respond to the galvanic current (constant) and there will be no response to faradic stimulation.

Therefore, only the galvanic current is used at this stage. Contractions are produced only on making or breaking the circuit, when this form of current is used, and so an interrupting device must be placed in series in the circuit. This consists of a metronome interrupter. An indifferent pad is placed in some convenient spot and the active electrode is applied to the muscle. The interrupter is regulated to give about sixty contractions a minute, and the treatment is carried out daily for about fifteen minutes. It does not matter whether the anode (+ pole) or kathode (— pole) is used as the active electrode. That pole which gives the best response with the smallest amount of current should be selected. Degenerated muscle is said to respond most readily when the positive pole is used and the current closed. This is not always the case. It is perfectly simple to change the polarity of the electrode by the reverse switch on the apparatus, and see which pole gives the best result in any particular case.

About 5–10 milliamperes usually suffice, but sometimes a larger amount of current is necessary to provoke contractions.

There is no need to remove the splints—if splints are being used. In the case of foot-drop resulting from division of the external popliteal nerve, the anterior group of muscles should be treated whilst the foot is held at right angles to the leg on a splint. Similarly, in paralysis of the extensors of the wrist due to musculo-spiral injury, the wrist should be kept dorsiflexed on a 'cock-up' splint during the treatment. Sufficient attention is not always paid to this point, and harm may be done by stretching the paralysed muscles if the joint is unsupported during such time as the muscles are undergoing electrical stimulation.

Faradism. At intervals of two or three weeks the muscles should be tested to see whether there is any return of faradic excitability. As soon as the muscles commence to respond to this form of current it should be employed, but the galvanic current must be used in addition.

The muscles will not regenerate all at once, but will be in a state of partial degeneration. The regenerated fibres—which have again taken on transverse striation—will respond to the faradic current, but those fibres which are still degenerated will not.

It follows that if the faradic current alone is used, as soon as there is commencing response to this form of stimulus part of the muscle only will be exercised. Whether the two currents are applied together, or consecutively, does not, I think, matter.

When the muscle reaches a further stage of recovery, and responds well to the faradic, this is the form of stimulus to be recommended.

The various muscles should be exercised as described in a previous chapter.

It is essential to know the position of the motor points, as it is by stimulation over these points that muscular contractions are most easily brought about. Although these points vary slightly in different individuals the diagrams are approximately correct. Stimulation over the motor points will give a contraction with quite a weak current, and one which will have no effect over other parts of the muscles.

Again, the points where the main nerves are nearest to the surface must be known, as sometimes contractions can be produced with a faradic current by stimulation over the nerve, when stimulation at the motor point fails to elicit any response.

The nerves most easily approached by this direct method of stimulation are:—

1. Musculo-spiral, in the groove on the back of the humerus as it winds around between the outer and inner heads of the triceps.

2. Ulnar nerve, behind the internal condyle.

3. Median nerve, under cover of the biceps in the upper and middle thirds of the arm.

4. External popliteal nerve, winding round the neck of the fibula.

Care must be taken that the recovering muscles are not stimulated to the extent of causing fatigue. For a group such as the extensors following musculo-spiral injury in the early stages about ten minutes' interrupted galvanic stimulation will be sufficient.

Where recovery has taken place to the extent of obtaining a faradic response about ten minutes' Graduated Contraction should be given. Treatment by electrical stimulation should be given once daily, and should continue, if circumstances permit, until such time as the patient regains functional use of the limb.

II. **Treatment by massage.** Massage treatment may be employed daily from an early stage.

The object is to promote nutrition by improving the circulation of the part, thus accelerating the removal of waste products and increasing the supply of oxygenated blood to the muscle. Deep kneading and pinching of the muscles are necessary, and the scar and site of the nerve suture should be avoided.

In those cases in which the patient cannot tolerate deep massage on account of pain light massage may be employed with benefit. Massage treatment should be employed for the whole limb and not only for the paralysed muscles. The limb both above and below the site of lesion should be massaged.

III. **Treatment by heat.** The affected limb should always be kept warm, wrapped in wool, and protected from the cold. In many of these cases the limb is cold—in some even it is cyanosed and blue—owing to defective circulation. Now one of the effects of cold is to hinder muscular contractility, not only voluntary power, but also contractions brought about by electrical stimulation. It follows from this that heat is of great value as an adjunct to treatment, in improving muscle, and in making more effective the other forms of treatment, *e.g.* massage and electricity.

Heat in some form—a basin of hot water will suffice—should be applied before massage or electrical stimulation.

The more modern methods of applying heat—diathermy, the 'Eau Courante', or the whirlpool baths—are all good, but require special apparatus which is not always obtainable. In practice either immersing the limb in a bath of hot water or letting water from the hot tap play over it will do all that is necessary.

In some nerve lesions heat will relieve pain, but in the so-called irritative lesions it generally has the reverse effect and is contra-indicated.

IV. **Treatment by exercises.** This is the form of treatment necessary when recovery is well advanced. The various forms of exercise are dealt with in the section on this method of treatment.

Whenever circumstances permit, assisted exercises, given by a competent masseuse, are of great value. If the masseuse is experienced the patient derives the greatest amount of value from the exercises and does not run the risk of exercising the recovering muscles to the point of fatigue.

In addition to the special exercises for the affected muscles general exercises are called for. This is especially the case in treating soldiers suffering from nerve injuries. The period of convalescence is long and irksome, and exercise, both physical and mental, is required. The training of patients in skilled occupations has proved of the greatest value, not merely in promoting recovery of the paralysed limb, but even more in assisting the 'morale'. In the workshops adapted for this purpose the men are given a definite, regular, and interesting occupation suitable to the capacity of each individual case, and time hangs less heavily on their hands.

The curative workshops, coupled with physical drill and specialized treatment for the affected limbs on the lines laid down, may, I think, be regarded as the ideal after-treatment for cases of peripheral nerve injury.

Gradual correction of deformity. It sometimes happens that contractures have already occurred as the result of inefficient after-treatment, or from some unknown cause, and must be overcome in order that a useful limb may result when there is recovery in the conducting power of the nerve.

These contractures should be overcome by the gradual method of correction, advocated by Robert Jones and already referred to, in discussing the treatment of joint conditions in which the lesion is intra-articular, *e.g.* subacute arthritis.

The principle consists in overcoming the contractures by gradual stretching by means of splints.

FIG. 340. FIRST STAGE OF HAND. THE FINGERS COULD BE PARTIALLY STRAIGHTENED BY FURTHER FLEXING THE WRIST.

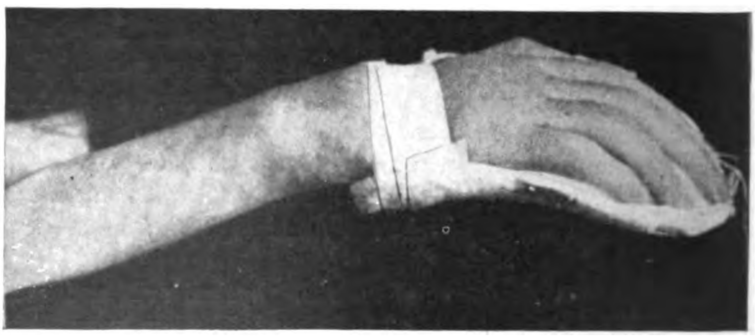

FIG. 341. SECOND STAGE. A WEEK LATER. FINGERS STRAIGHTENED ON PLASTER HAND SPLINT.

To make the matter clear, this method of treatment as applied to an actual case will be described in detail, and the same principles may be applied in dealing with other joints.

Case H.—**Paralysis and contracture of the hand following brachial plexus injury.** The disability consisted in inability to dorsiflex the wrist, or to extend the fingers, which were flexed slightly at the metacarpo-phalangeal joints and markedly at the interphalangeal. The wrist was palmar-flexed at an angle of about 50° and could not be dorsi-

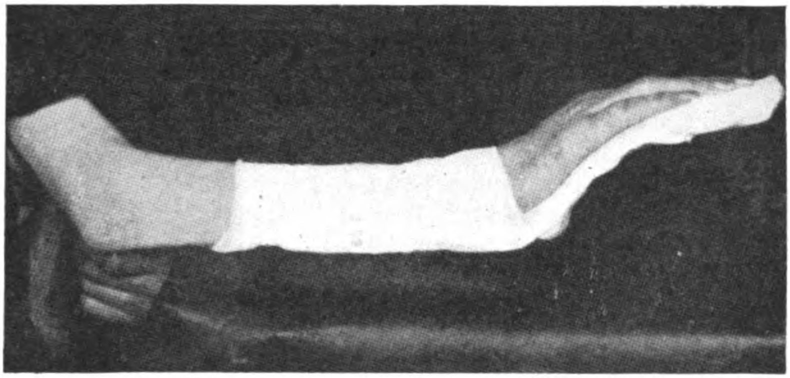

FIG. 342. THIRD STAGE. CORRECTION OF FINGERS MAINTAINED, AND WRIST DORSIFLEXED ON LONG 'COCK-UP' SPLINT.

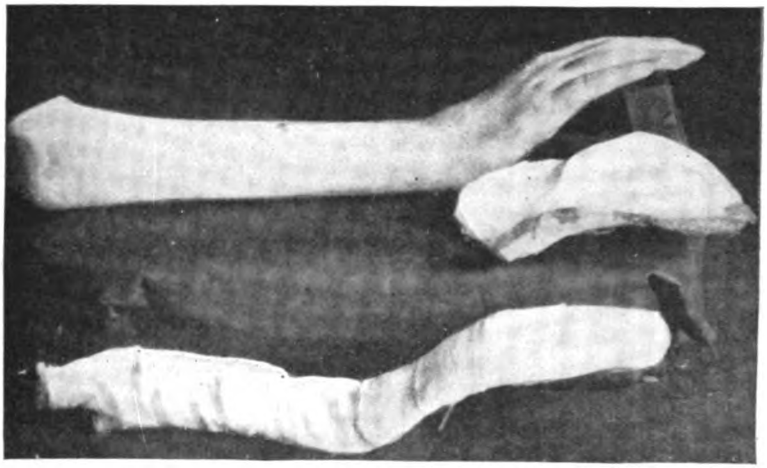

FIG. 343. FOURTH STAGE. POSITION OF HAND AND WRIST CORRECTED, AND EASILY HELD IN CORRECTED POSITION. Shows plaster hand splint and long 'cock-up'.

flexed. This deformity could not be corrected by manipulation or passive movement.

By still further flexing the wrist partial correction of the distal deformity was possible, and a plaster of Paris splint was moulded to the palmar surface of the hand and fingers in their corrected position. When the plaster had set sufficiently to retain its shape it was carefully taken off, trimmed and allowed to harden, being reapplied by means of adhesive strapping.[1]

The contracture of the fingers being thus overcome and the recurrence prevented by the splint, attention was next devoted to overcoming the flexion deformity of the wrist.

A metal splint was applied, taking purchase from the anterior surface of the forearm above and from the hand splint below, and the wrist was bandaged firmly to this splint, a pad being applied over the dorsal convexity of the joint—the pressure thus tending to correct the deformity. As soon as this bandage became loose—as the joint commenced to straighten out under the pressure—it was reapplied more firmly.

In this way the flexion deformity of the wrist was overcome, and the hand and forearm were got into a straight line. At this stage the use of the separate hand splint was discontinued and a metal splint was applied to the palmar surface of the forearm and hand.

Wedges of felt were next placed between the palm and the splint to force the wrist joint into a position of dorsiflexion. These wedges were placed well up in the palm so as to avoid the production of hyperextension at the metacarpo-phalangeal joints. The splint was then bent to fit the hand in its new position and more wedges employed until the required degree of dorsiflexion was obtained. In this way the various structures were stretched in the order of their tension, and when the corrected position was attained the hand was kept in this position until all liability to recurrence was passed.

In the case of true ischæmic paralysis the same method is employed, but the correction of the distal deformity may necessitate the use of several plaster splints as the contractures of the fingers are gradually overcome, or small metal splints may be applied to each separate finger.

The principle is the same in dealing with many other deformities, various forms of splints, either of metal or plaster of Paris, being employed, and the position of the limb gradually corrected by constant pressure in the required direction.

[1] Captain Naughton Dunn kindly showed me this method of correction of deformity with plaster splints, and it is with his permission that I am describing it here.

CHAPTER VI

FRACTURES

I PURPOSE writing quite briefly on the application of the Graduated Contraction method in the treatment of fractures, in order to show how this method may be usefully employed, both in shortening the after-treatment and in preventing some of the common causes of failure, provided that the two great principles—viz., reduction of deformity with correct alignment and prevention of recurrence of deformity by correct splintage—are carried out.

Speaking generally, if the deformity is reduced, and the fragments are placed and maintained in correct alignment, the results are satisfactory.

It is the failure to carry into practice these well-established principles that is, in the main, accountable for the many poor results that are met with.

In fractures, either actually involving joints or occurring in their neighbourhood, something more is needed in the way of treatment. If these fractures are kept immobilized in splints until union is firm, the joints become stiff and the muscular atrophy is extreme.

This can be obviated by the method advocated, and there are many advantages, and as far as I know no disadvantages, from its use; for in treatment of these conditions by Graduated Contraction—

(i) Splints need not be removed, and therefore the fracture is not left unsupported, nor is there any possibility of recurrence of deformity from this cause.

(ii) Atrophy is reduced to a minimum, a matter of very real importance, as affecting the period of time during which the patient is incapacitated. The atrophy is not entirely prevented. What was called 'active wasting', in speaking of sprains, goes on in this case also. But the fact that the muscles are gently exercised, almost from the beginning, largely prevents disuse atrophy; and the tone is maintained, so that, when the union is sufficiently firm to bear the body weight in the case of the lower limb, or to allow of the using of a joint in the case of the upper, there is not that prolonged period of convalescence during which time the patient has to tone up and re-educate his wasted muscles.

(iii) Stiffness in joints is obviated, for from the first the joints are gently moved by the physiological contractions of the patient's own muscles.

Moreover, the formation of adhesions, both between the tendons and their sheaths, and between the tendon sheaths themselves and the surrounding structures on which they rest, is prevented.

The trauma which was accountable for the fracture probably damaged the joint structures as well, although it may be in only a minor degree.

Now a joint injured, no matter how slightly, and kept long at rest almost invariably becomes stiff from the formation of adhesions. It may be thought that a joint surface damaged by, say, a T-fracture running into it, is liable to further changes if early movement is allowed. This is not my experience, and in the skiagram shown of R., which may be taken as an example, the joint surface is pretty considerably involved. Now this case was treated by Graduated Contraction, which was commenced forty-eight hours after the accident. He had been injured in a motor accident, and there was considerable damage to the ligaments and structures of the wrist-joint, with much swelling and some pain.

This wrist was moved gently, by the contractions produced by stimulation of his own muscles. The contractions allowed were quite small, being gradually increased, so that at the end of a week about twenty degrees of flexion and a similar degree of extension were obtained.

The functional result was excellent, practically the only loss of movement remaining some six months later amounting to a few degrees of dorsiflexion, which in no way interfered with good functional use of the wrist and hand. No forcible manipulation was necessary at any period in this case.

I never hesitate to move the joints in these cases, and the important point is to insure that the movements produced by stimulation of the muscles are painless. Any irregular or complete movement would necessarily be painful and would do harm. Painless movements are all that are necessary to keep the joint and tendons free, and their range can be gradually increased from day to day. Any forcible manipulation is contra-indicated.

(iv) Callus is not formed in excess. An examination of the skiagram in the case just recorded is evidence of this, particularly as this is just the type of case in which any excessive callus formation is to be looked for and guarded against.

In none of my cases treated on these lines has the callus been excessive, or given rise to trouble afterwards.

In the early stages the treatment by massage and passive movements has been much advocated of recent years.

If this form of treatment, as first scientifically described by Championnière, be carried out without due precaution and care, it will end in disaster.

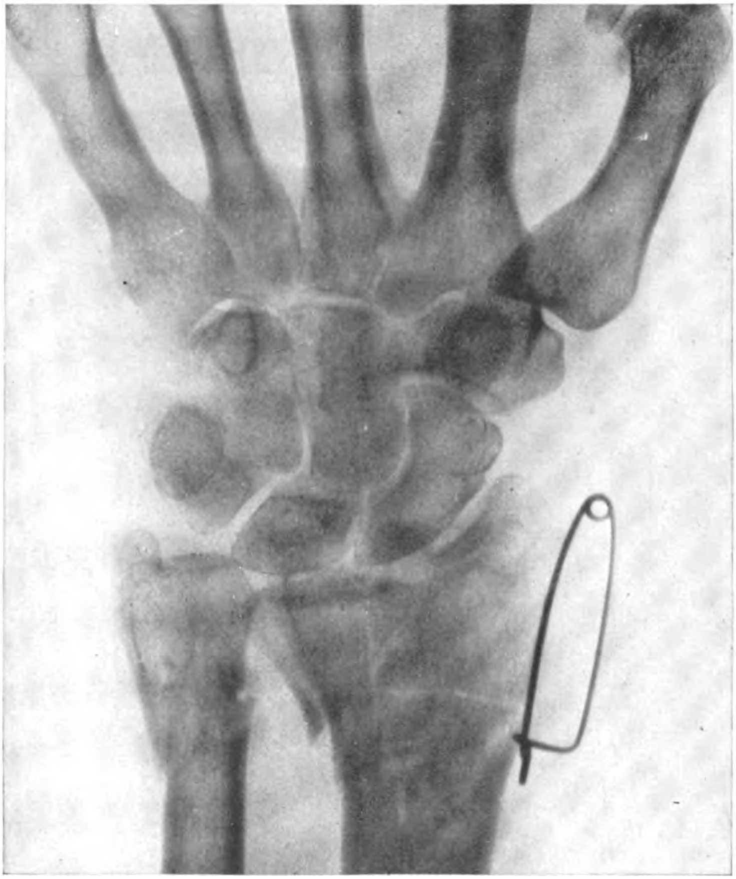

FIG. 344. COMMINUTED FRACTURE OF LOWER END OF RADIUS AND ULNA—SHOWING INVOLVEMENT OF JOINT SURFACES.

Dr. Mennel writes of Championnière as 'strongly deprecating the idea that the treatment of fractures may be left in the hands of the ordinary masseur. Were it necessary so to leave it, he says very plainly that he would be the first to advocate the continuance of the older methods of treatment as entailing less risk of injury to the patient than would be involved by massage at the hands of most of its professors.'

In all cases, and so, for example, in a case of Pott's fracture, splints must be discarded for massage and mobilization treatment, during the actual time this treatment is in progress. If there is fear of reproducing the deformity, massage and mobilization are postponed.

FIG. 345. SAME FRACTURE TWO YEARS LATER. Showing no excess of callus or arthritic change in the joint. This is of interest, as this case was treated by movements by graduated contraction from the commencement, and the function of the wrist was almost perfect.

This early removal of splints constitutes to my mind a possible danger, and is most certainly a danger in the hands of people who are not constantly handling fractures. Again, the muscle wasting which goes on is considerable, and the gentle massage, stroking, which is advised, has but little if any effect on this.

As in the case of sprains, massage is of the greatest use in getting rid of the œdema and relieving the pain. It should be commenced from the earliest possible moment. Only gentle massage is permissible, and the splints should not be removed entirely for this purpose, but rather half at a time, the limb being immobilized against the remaining half by an assistant as described in the treatment of a case of Pott's fracture which follows.

The ideal treatment of a fracture consists in:—

(i) Reduction of deformity.

(ii) Prevention of recurrence of the displacement by the necessary splintage.

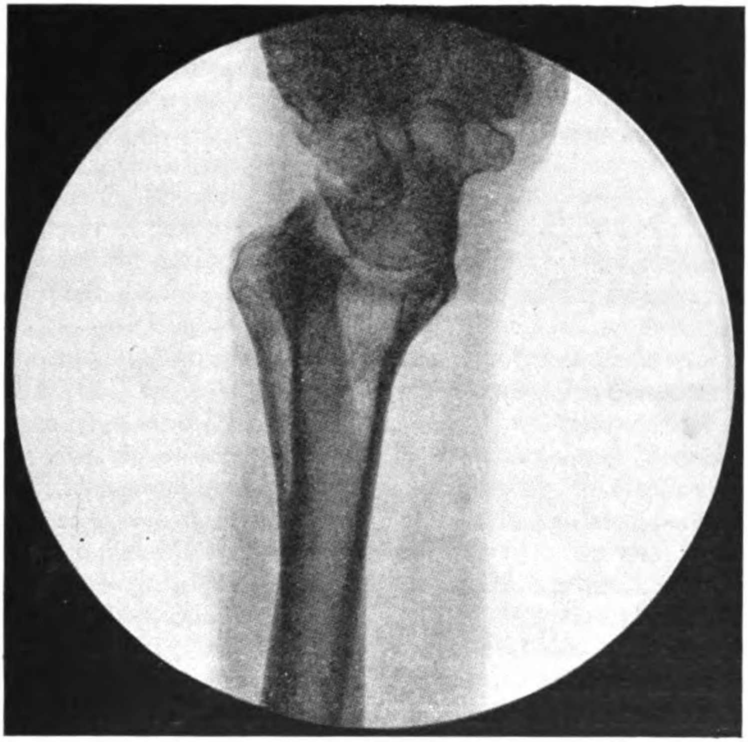

FIG. 346. LATERAL VIEW OF THE SAME CASE.

(iii) Relief of pain and removal of œdema by gentle massage.

(iv) Prevention of muscle wasting and of adhesions by Graduated Contraction.

The pros and cons of operative and non-operative treatment of fracture are not within the scope of this chapter. It is sufficient here to say that the reduction must be effected and good alignment obtained, especially in the lower limb, if a good functional result is to be attained.

A mal-united Pott's fracture is a crippling deformity, and no treatment of muscles will ever be effective if this deformity remains uncorrected. Once the bony deformity is corrected by operation, the leg muscles should be built up again, and in this way a good functional result is obtained.

The reduction of deformity and the prevention of redisplacement by splintage are considered by some surgeons to be quite sufficient, and they are content to dispense with all early massage and movements if these are assured.

But I see no reason in thus allowing atrophy and the formation of adhesions to occur, when both can be in the main prevented without risk.

Marked deformity of the wrist following an unreduced Colles's fracture may and often does exist, and if there is any contra-indication to reduction and the case is treated by massage and stimulation of the muscles, it may, and frequently does, yield a good functional result.

This is well shown in the case of a man who was brought to me in December, 1910. He had sustained a Colles's fracture six weeks before, the deformity was not reduced, and his wrist had been immobilized in splints. The lower fragment was impacted and the deformity marked.

The movement was poor and limited, and the power of gripping and general strength in the hand were very little.

The patient refused operation, as I told him I thought he could get a useful hand without, and time was of the utmost importance. He was treated by Graduated Contraction, massage (or rather unskilled rubbing at home) and exercises, and made to use the hand, and this he was doing freely in a fortnight. In five weeks, except for the obvious deformity, he was cured. That is to say, the hand was quite strong with good movement, and the result as far as function was concerned, was excellent.

He reported three months later that the wrist gave no trouble, and he was just as capable as a wage-earner as before.

The treatment of the muscles is only part, but I think an important part, of the whole treatment of a case of fracture.

Take the actual treatment of a Pott's fracture which has been reduced under an anæsthetic, and in which the X-ray examination at this stage shows perfect reduction.

The leg and foot are immobilized in a plaster splint (Croft's method) hinged down the back and cut down the front, the whole being held in place by a bandage.

This splint can be removed from one aspect of the leg, *e.g.* the outer, whilst the foot and leg are kept firmly immobilized against the inner half, the hands of the assistant replacing the outer half of the plaster case.

There is no question of leaving the leg unsupported, or altering the relation of the leg and the dorsiflexed and inverted foot. They are held to the splint just as firmly and surely as though the whole splint were in place.

The muscles on the outer side are gently contracted. (Cf. Figs. 325, 326, 327, in treatment of acute sprains of ankle-joint.) For the first week only minimal contractions are permitted and no complete or sudden movement of the ankle is allowed. The tendons are moved in their sheaths and the structures surrounding the capsule are gently pulled on.

When the anterior muscles have been exercised the external part of the plaster splint is reapplied and the leg immobilized against it by the assistant, whilst the inner half is removed and the calf muscles stimulated.

An excellent example of this was published by Dr. Smart and myself in the *Lancet*, 1912:—

Case 8. **Pott's fracture.** September 29th, 1910. The patient was a short, heavy man with Pott's fracture of the fibula, and a good deal of displacement. Fracture put up under an anæsthetic on the 29th. Immobilized in a Croft plaster of Paris splint with hinge down the back. X-ray photograph showed bones to be in excellent position. Four days later treatment of the muscles of the leg by Graduated Contraction was commenced. One side of the hinged splint was carefully removed, and the leg held immobilized to the remaining part of the splint by the nurse. The muscles were treated for ten minutes; then the splint was reapplied to that side and removed from the opposite side of the leg and the remaining muscles treated. The patient walked with the aid of two sticks in five weeks, and nine days later gave up the sticks and walked perfectly without support.

Further X-ray photographs showed that the bones had united in perfect position and the patient made a complete recovery, and reported twelve months later that he experienced no disability as the result of the accident. The amount of wasting in this case was very slight. The calf on the injured side at the end of a week was only slightly smaller than the other, and the tone of the muscles was recovered very quickly. The ankle-joint was moved from the first by the muscular contraction. The slight amount of movement, which must of necessity have taken place between the bone ends at the site of fracture, gave rise to no pain and did not cause excessive callus formation.

It may be thought that the patient was allowed to bear weight on the limb too soon. I can only say that the result in this case could not have been improved upon. It may be that the more active treatment suggested improves the local circulation and physiological nutrition of parts, and so hastens the consolidation of callus.

The other point of importance is that the condition of the muscles was such that the tendons were able to take their part in supporting the joint, and an abnormal strain was not thrown on the ligaments, as is usual after a period of immobilization. Without this support, the ligaments would have stretched in all probability, and certainly but for the condition of the muscles a much longer convalescence would have been essential.

CHAPTER VII

NOTES ON SOME FRACTURES AND DISLOCATIONS

I. **Fractures and fracture dislocations of the carpal bones.** Fractures of the carpal bones are common, but are very often unrecognized, and especially if no X-ray examination is made of the supposed 'sprained wrist'.

The commonest fracture in this situation is fracture of the scaphoid, and this is fairly often complicated by dislocation forwards of the semilunar.

The wrist must be put up in dorsiflexion, and sometimes mal-position of one of the fragments prevents this. In this case, if forcible manipulation fails, the scaphoid must be cut down upon and the offending fragment removed.

The results of excision at a later stage are not so good, and there is a tendency to arthritic changes in the joint accompanied by pain and weakness in the wrist.

If the semi-lunar is dislocated, unless reduction can be effected it should be removed.

An interesting case of this dislocation, occurring as a separate lesion and uncomplicated by fracture, is the following:—

The patient, W. H. C., aged 48, on December 13th, 1910, fell down two stairs, bruising his side, damaging his left wrist, and cutting his head.

His head condition and bruised side rapidly recovered, but the wrist remained swollen, painful, and with marked limitation of movement.

An X-ray examination was held, but no fracture was discovered, and the case was regarded as one of a severe sprain of the wrist. Massage and movements were tried, but these caused considerable pain and produced no beneficial result.

I first saw the patient seven weeks after the accident.

The left wrist was thickened and there was a prominence just on carpal side of radio-carpal joint and deep to the flexor tendons. There was well-marked synovitis of the flexor tendon sheaths.

This part of the wrist was tender on pressure.

The styloid processes of the radius and ulna were normally placed, but the palm appeared to be shortened when compared with that of the opposite side.

There was no tenderness or swelling in the anatomical snuff-box to indicate fracture of scaphoid.

The movement at the wrist and mid-carpal joints was markedly restricted. Flexion was almost nil, extension was limited to a few

FIG. 347. ANTERIOR DISLOCATION OF SEMI-LUNAR, WITH NO OTHER BONY LESION. ANTERO-POSTERIOR VIEW. Note the anterior horn of semi-lunar, superimposed over the os magnum. The dislocation can be recognized from this view, although more clearly shown in Fig. 348.

degrees of movement, and abduction and adduction of the hand were limited, although to a less extent. On attempting any forcible movement great pain was experienced and also a tingling of the fingers over the median nerve area.

The grip with the left hand was very poor, and there was very marked wasting of all the muscles of the forearm. These muscles at once went into spasm on attempting forcible movement of the joint.

An X-ray examination showed clearly an anterior dislocation of the semi-lunar bone.

FIG. 348. ANTERIOR DISLOCATION OF SEMI-LUNAR. LATERAL VIEW.

There was no fracture of the scaphoid.

The position of displaced semi-lunar was such that the facet for articulation with radius looked directly backwards and the concave facet for the os magnum directly forwards.

Under the anæsthetic no further movement was possible. Attempted reduction was not successful. When the muscles were relaxed under the anæsthetic the obstruction to the joint movement was obviously bony.

An incision two inches long was made immediately to the ulnar side of the palmaris longus tendon. Palmaris longus tendon and median nerve were retracted outwards, the other flexor tendons inwards. The semi-lunar bone was found lying between the flexor longus pollicis and flexor profundus digitorum with the concave articular facet for the os magnum looking directly forwards—the position which the skiagram had previously shown the bone to occupy.

The semi-lunar had come forward through the capsule of the wrist-joint, which had completely closed behind it.

The bone was lying free except for two strong ligaments holding it to the scaphoid on the radial side.

These ligaments were divided and the semi-lunar was excised.

After the operation, the movement at the wrist-joint was quite free and full flexion was possible. The joint was bandaged up in a semi-flexed position.

The muscles of the forearm were treated on the sixth day by Graduated Contraction, and the wrist and mid-carpal joints were moved.

The treatment was carried on for six weeks, the amount of movement being gradually increased. At the end of this period the movement at the joint was excellent, and extension, abduction, and adduction were complete. Flexion was almost full, about seventy degrees, showing that both the wrist and mid-carpal joints were functionating. The wrist-joint was strong and the patient was able to do anything with the hand, and suffered no ill-effects from the injury.

The prolonged after-treatment in this case was necessary owing to the fact that during the seven weeks between the injury and the time of operation very marked wasting of the forearm muscles had taken place.

In cases in which the scaphoid is fractured in addition, and especially when recognized for the first time some time after the injury, a guarded prognosis should be given. The functional result will probably be satisfactory, but the movements at the wrist-joint are not likely to be quite as good as before.

II. **Fracture of the scaphoid of the tarsus.** Fractures of the os calcis, astragalus, and metatarsals are common, but fracture of the scaphoid bone of the tarsus is a less frequent injury.

I mention this case as it is somewhat unusual, and as the fracture was ununited.

The history was, that fourteen days before the patient had slipped in endeavouring to get on to a moving omnibus. He did not fall, but failed to board the omnibus and walked with a limp to the station. The pain was severe and the whole foot swelled some three hours later. He had remained at home for a fortnight resting and massaging the foot, which improved each day, but did not recover completely.

On examination the foot was somewhat swollen, and a thickening was noticed over the scaphoid. He walked with a limp.

The X-ray examination showed the fracture (see figure).

The previous history was that thirty years before when at school he had damaged the foot jumping a hurdle in his school sports. He was not laid up at the time but limped about, and the accident having occurred in March he played cricket at school that summer.

FIG. 349. FRACTURE OF SCAPHOID OF THE TARSUS, UNUNITED AND WITH DORSAL DISPLACEMENT OF THE UPPER FRAGMENT.

The foot had been ' weak ' ever since, and having tried various apparatus under different advice from time to time, he had eventually ceased to do anything for the condition, and had regarded the foot as permanently weak, but had played golf, &c., and got about normally.

From the history and from examination of the skiagram it is almost certain that the fracture occurred in the first injury thirty years before, and that the recent injury was simply a sprain superadded to a weakened foot.

He was treated with massage, Graduated Contraction, and exercises, and recovered so as to regain his own normal standard in a fortnight.

The case is interesting from two points of view. First, the comparative rarity of the lesion, and, secondly, the effect of restoring the musculature in a condition in which this was not the only part affected.

III. **Dislocation of acromio-clavicular joint.** I mention this simply to call attention to the results of treatment.

Dislocation of the clavicle at this joint is very easy to reduce, but great difficulty is experienced in preventing recurrence of the deformity.

To so great an extent is this the case that treatment by operation is sometimes advised, so that the joint surfaces may be kept in apposition by wiring or similar fixation.

This procedure is seldom if ever necessary, and markedly interferes with movement of the arm.

In my experience the results of prolonged fixation are not very good. The deformity usually recurs, and if by immobilization the shoulder-joint—damaged probably to some extent at the time of the accident—is allowed to get stiff there will be some difficulty in producing a good functional result.

I have notes of several cases, and in all of them deformity was noticeable and yet the function as a result was good.

The arm should be fixed to the side by a bandage, and a second support should pass from the elbow over the shoulder, with a pad over the acromio-clavicular joint.

Massage should be used from the commencement, and gentle movements of the shoulder and elbow produced, either passively by hand or physiologically by Graduated Contraction. The hand is in use throughout and not kept at rest.

Neither for this condition nor yet for fractured clavicle is Sayre's method of strapping with the forearm fixed across the chest to be advised. The report on one of my cases seen a fortnight after the accident, is as follows:—H. F. Fall on to shoulder, off a bicycle, October 30th, 1913. In bed for a fortnight, as in the early stages there was some doubt as to the diagnosis.

When I saw him there was marked deformity, with a stiff shoulder.

He was treated by Graduated Contraction for a fortnight, with massage and exercises at home during this period.

The result was excellent as regards function. The shoulder movements became free with use, and the breaking down of weak adhesions by muscular action.

Six weeks later he reported the arm was as good as before, and again six months later a like report was given.

The point I wish to bring out in this connexion is that if prolonged fixation, with the idea of reducing, and keeping reduced, the dislocation of the joint had been insisted on, the patient would have had in all probability the same degree of deformity and in addition a stiff shoulder,

FIG. 350. DISLOCATION OF ACROMIO-CLAVICULAR JOINT. This skiagram was taken after the patient had obtained a perfect functional recovery, and shows the common sequel, viz., permanent deformity.

which would have been most difficult to cure; particularly so as forced movements would have again strained the recently damaged acromio-clavicular joint.

IV. **Treatment of fractured clavicle.** By far the best method is that of Wharton Hood, described by him in his book on the 'Treatment of Injuries', published some years ago.

In Sayre's method the whole forearm and hand, in addition to the shoulder, are immobilized in the strapping, and this is unnecessary and tends to promote acute discomfort during treatment and to prolong the convalescence.

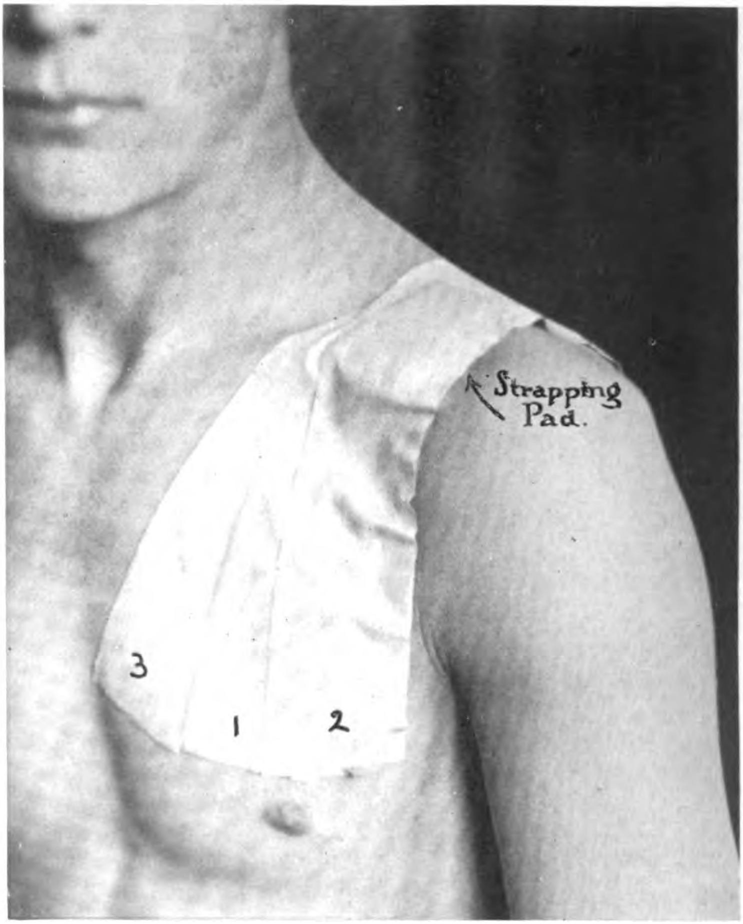

FIG. 351. STRAPPING OF FRACTURED CLAVICLE (FRONT VIEW) AFTER WHARTON HOOD'S METHOD, BUT WITH THE ADDITION OF A SMALL PAD OVER THE SITE OF FRACTURE. The strips are put on in the order shown, as numbered in the figure.

Wharton Hood's method consists in immobilizing the fragments, after reduction of the deformity, by strapping applied directly over the site of fracture.

Three strips of arm adhesive plaster are applied, each one and a half to two inches wide. The first is applied as follows: Commencing at a point immediately above the nipple in front, it passes directly upwards, over the fracture, and down over the dorsum of the scapula behind, to a point just below the angle of that bone.

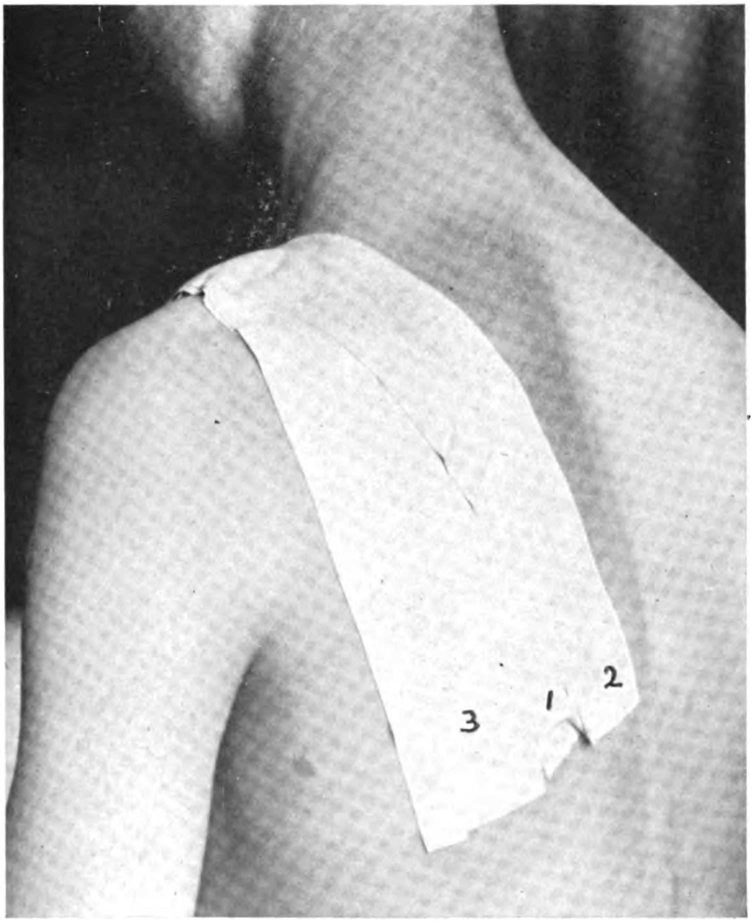

FIG. 352. SAME—BACK VIEW.

Two lateral strips are then applied, one just to the inner and one to the outer side of the first strip, and slightly overlapping it. These strips converge over the seat of fracture and diverge slightly below. A small pad, made of half-a-dozen thicknesses of sticking plaster, as shown in the figure, placed sticky side out to allow of good fixation, put on over the site of fracture, will assist fixation of the fragments.

The arm is supported by a sling, and the hand may be used from the first.

Massage treatment is commenced at once, the limb being massaged without disturbing the strapping. As the latter tends to become loose in a few days, it is removed and fresh strapping applied.

Underhand movements can be commenced gently from the first.

FIG. 353. FRACTURE SURGICAL NECK OF HUMERUS, UNRECOGNIZED FOR FIVE WEEKS.

The patient should be able to do most things at the end of a fortnight, being careful not to strain the arm by lifting, &c.

At the end of three weeks the arm should be strong and all movements free.

V. **Fracture of surgical neck of humerus in a boy.** This case, of which the skiagram is reproduced, is interesting from the history. The boy fell out of a tree, and injured the arm and shoulder, on July 2, 1913. His mother was told 'he had bruised the arm badly', and it was 'rubbed night and day with some kind of lotion'.

Five weeks later he came to hospital on account of the complete wasting of the arm, with paralysis of the deltoid.

The case was at first regarded as injury to the circumflex nerve, but a skiagram at once cleared up the diagnosis, and I would again emphasize the necessity of an X-ray examination in these cases of joint injury.

The adhesions, which were slight, were broken down without any anæsthesia, and the muscles of the arm and shoulder girdle were treated by Graduated Contraction. At the commencement of treatment the deltoid wasting was most marked, but the muscle reacted normally to the faradic current.

He recovered complete function in three weeks.

CHAPTER VIII

TREATMENT BY MASSAGE AND EXERCISES

THE scope and usefulness of massage treatment in dealing with acute sprains has been indicated. In acute lesions massage has a very definite use. It is the main therapeutic agency for reducing œdema and alleviating pain.

Light massage. The effleurage of the French writers is a very gentle stroking movement. It is the only form of massage to be recommended in dealing with acute lesions, and in these any vigorous rubbing will be painful and is contra-indicated. In acute cases—sprains and the like—massage must never give rise to pain. In competent hands it has the reverse effect.

Deep massage. The various manipulations have been described as: (i) *Pétrissage,* which consists in kneading and in pinching up parts of the muscle; (ii) *Tapotment,* hammering or percussing the muscles with the fingers or the ulnar border of the hands; (iii) *Friction,* circular movements usually made with the tips of the fingers; (iv) *Vibration,* which may be performed either with the hands, or with the aid of instruments of various kinds—vibrators.

Deep massage should never be ordered in acute cases, but it is the form of massage to be recommended when dealing with chronic conditions, *e.g.* the dispersal of the semi-solid œdema, so often present after severe injuries or in neglected cases, and for which the gentle stroking is of little use.

Deep massage acts by accelerating the venous and lymphatic circulation, and so increasing the supply of oxygenated blood to the part. It is of service in reducing thickening and in breaking up inflammatory products. By its effect upon the blood supply, it aids in muscle regeneration.

The two forms of treatment, massage and exercises, are almost always referred to together, and in this way I think their functions have been confused, and the common mistake made of attributing to these two very distinct therapeutic agencies the same effect.

For redevelopment of wasted muscle, exercises are of the utmost value, whilst massage, in comparison, is of little use, although assisting, by its action on the blood-vessels, in maintaining the nutrition of the parts.

In treating the later results of injury, when the main object of treatment is to redevelop and re-educate wasted muscles, active exercise against resistance is the ideal method, but a badly strained or much-wasted muscle is incapable of performing active exercise.

In dealing with a group such as the adductors, it is quite possible, and in practice it is common, to find one member of the group, usually the adductor longus, strained, elongated, and lacking in tone, and so incapable of performing complete voluntary contraction. This is noticeable only in certain movements—in this case gripping the saddle when riding.

If exercises are ordered and the patient is made to practise adduction exercises, such as raising a weight *via* a pulley, the action is performed by the undamaged members of the group, the strained adductor longus not taking its due share in the exercise.

The failure of treatment in this case is not apparent until the particular muscle is called upon. The patient can adduct quite well and strongly, but if he rides again, and puts a sudden strain on the muscle, as is experienced when a horse swerves at a fence, or pecks on landing, the disability and pain immediately recur.

Cases are sometimes met with in which one would suppose that massage and exercises were all that were necessary, and yet the patients have been treated by these methods for a month or longer with little benefit. The following case is of interest in this connection. In February, 1911, I saw a lady who, two and a half months before, had sprained her left ankle. It was a simple sprain. She had been seen at the time by a competent surgeon, and a skiagram had shown that the sprain was not complicated by a fracture of the fibula. During the two and a half months between the time of her accident and her visit to me she had been having massage and exercises daily, but in spite of this treatment she was unable to walk more than a hundred yards on account of pain, and in addition complained of considerable pain in the ankle and up the leg.

The anterior tibial and peronei muscles were markedly wasted, but movement at the joint was complete in every direction and there were no adhesions. She was treated by Graduated Contraction for a fortnight, and could then, she stated, 'walk a mile'. At the end of three weeks she was told to discontinue all treatment and simply walk and use the leg. She complained of pain for a week longer, and then was completely cured.

The anterior tibial group had hypertrophied to an extraordinary degree, and overlapped the crest of the tibia, the muscle being actually developed in excess of that of the other leg. Six months later she wrote to me and said she had had no further trouble with the leg.

With the exception of these cases, in which one member of a muscle group requires redevelopment out of all proportion to the other members of that group, and in these cases as well, when the recovery has been sufficiently advanced, well-planned exercises will complete the cure and are to be recommended.

The consideration of exercises for this purpose may be discussed under two heads:—

(1) The Ling system of medical gymnastics or some modification of this system.

(2) Exercises, with apparatus.

Whichever form is recommended, and both have their uses, it is first absolutely essential to their ultimate success that the patient himself take an intelligent interest in their performance.

It is quite easy for him to carry out a whole series of carefully planned exercises in a slipshod and careless manner and to derive little or no benefit from their performance. Not only must he be taught the exact method of carrying out each individual exercise, but he must be supervised during its performance by someone capable of instructing him, in order that the position and the attitude of the body as a whole may be correct.

Both these provisos are absolutely essential if the treatment by exercises is to assist, and take its proper place as an adjunct to the treatment of the injury, and be the final stage in perfecting the cure.

The most useful form of exercise for the muscles which govern the ankle-joint are tip-toe exercises. First standing with heels together and toes apart, and rising on the toes some ten times. Then, after an interval of rest, repeating the exercise with toes together and heels apart.

I always insist on the patient holding the position, in this case on his toes, whilst he counts three slowly, and relaxing absolutely for a similar period before repeating the movement. Inversion exercises, raising the inner border of the foot, should follow.

There is no objection to his steadying himself by holding a chair whilst performing both these and the following exercise for the thigh muscles. To exercise the quadriceps the patient stands at attention, rises on his toes, and then fully flexes the knees, assuming the squatting position.

This position he holds whilst counting 'one, two, three,' and then slowly returns to the original position. This exercise is of great value for the quadriceps, and once all the members of that group are functionating is to be recommended.

At first the full squatting position cannot be attained, and most of the weight and strain will be borne by the normal limb. This is gradually overcome, but for some little time the patient must retain his balance by holding on to some support with his hands.

If the weakness is very marked and there is lateral mobility of the joint, the exercise can be done in a similar way, but with less strain on the joint. The feet are placed parallel to one another about six to eight inches apart, and the knees also are kept parallel, and pointing directly forward all the time. This obviates the rotation of the joint, noticeable in the preceding exercise.

The other important and simple exercise which requires no apparatus is 'climbing the wall'—for limitation of movement or weakness of the shoulder-joint. The patient, being unable to raise his arm above his head by voluntary muscular effort, stands facing a wall or door and puts the hand of the affected side as far up as possible. He then endeavours to get it still higher, by working up with his fingers. When he has reached the limit, he fixes the hand with his other hand, and, bending his knees slightly, allows the body weight to exert a pull on the joint.

These are simple exercises which an intelligent patient can carry out for himself on being shown exactly what to do.

The so-called 'duplicated exercises' require an assistant, and one trained to co-operate intelligently with the ideas of the surgeon. The exercises are of two types, the first in which the patient's feeble attempts at voluntary movement are assisted by the masseuse, and the second in which his stronger efforts are resisted, and so the muscles given more work to do, in performing the movement.

These duplicated exercises, if they are to be successful, require a high degree of skill on the part of the assistant, usually the masseuse. Especially is this the case in the second class 'resisted'. In these resisted exercises two types are practised.

In the one the patient's active muscular effort is resisted by the masseuse, and in the other the masseuse makes a movement—*e.g.* flexing or extending the forearm—and the patient, grasping the wrist, resists, calling into play those muscles which are in need of development.

It is in the application of the correct amount of force by the assistant that the special skill lies. This must never be such as to cause the patient to strain his recovering muscles.

Unless a skilled assistant, and one who can be relied on to use the right amount of resisting effort, can be obtained, duplicated exercises should not be attempted. They will not only fail to do good, but will do actual harm and delay recovery.

Exercises by means of apparatus. All that is really necessary in the way of apparatus is of the simplest type, and, once the principles on which it depends are grasped, may be made by a local carpenter at a very small cost by means of weights and pulleys. Large and costly machines are on the market, the best known of course being the Zander apparatus, some cheaper and less cumbersome modifications of which are now made in Paris.

The cost of the Zander machines and the space necessary for them prevent their being used except in large institutions.

They can be quite well replaced by the weight-and-pulley apparatus.

By a suitable arrangement of weights and pulleys any desired group of muscles may be exercised. The details necessary can be worked out for each individual case, the patient lying, sitting, or standing before the apparatus.

Either a webbing, stirrup, or handle serves as an attachment for the patient, depending on whether it is the lower or upper limb or limbs which he is to exercise.

For exercising the fingers and wrists, nothing equals the roller, fixed some four feet from the ground, with a cord carrying a weight attached and so arranged that the cord gradually winds up on the roller as this is turned. A ratchet is attached to the roller at the end, allowing it to rotate in the required direction only at any one time. An over- or under-hand grasp of the roller will exercise the flexors or extensors as desired.

The circumference of the roller itself should be varied at different parts, to allow of the fingers grasping it, even when their complete voluntary flexion is not obtainable. Eight inches at the large end and four and a half at the small will be a convenient size.

For exercising the individual fingers, practising on a typewriter machine or piano playing are either of them excellent, or some simple exercise can be devised, calling for individual movements on these lines.

Treatment by heat. Used in combination with massage, the various applications of heat are useful, but they are only an adjunct to treatment, and should be regarded as such.

The injured joint should be treated by some form of heat, before massage, and in many cases before electrical treatment. This is particularly necessary in dealing with cases of peripheral nerve injury.

In discussing Hutton's methods, Wharton Hood describes how he invariably poulticed the joint for a week before performing any manipulative treatment.

The more modern methods of applying heat, either by radiant heat, diathermy, or the newest of all, the ' Eau Courante ' and whirlpool baths, are all useful.

They tend to relieve pain and give the patient a general sense of comfort. They produce local hyperæmia, lasting for a varying period.

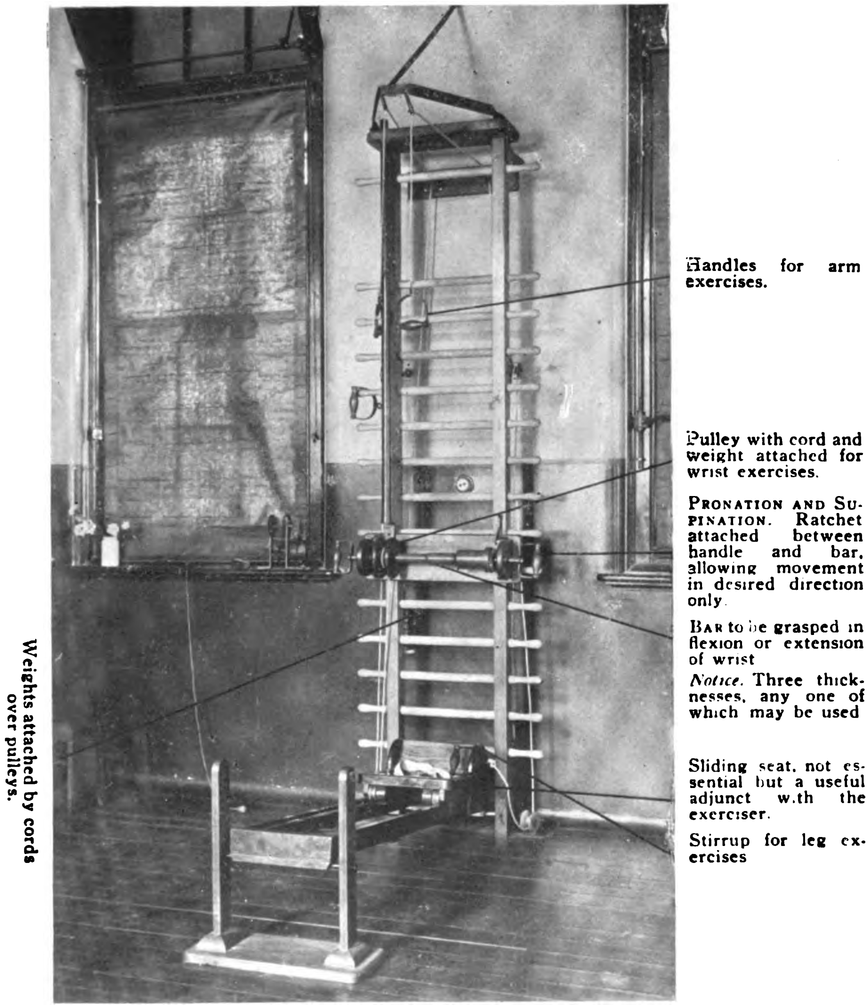

FIG. 354: COMBINED MACHINE FOR WEIGHT-AND-PULLEY EXERCISES AND WRIST ROLLER. This machine was devised by Dr. Mennel, and allows for all forms of exercise. Any part may be used separately.

It combines in one apparatus—

(1) The weight-and-pulley apparatus.
(2) The roller for wrist exercises of flexion and extension.
(3) Supination and pronation exercises.
(4) The ladder.
(5) Sliding seat.

The treatment of stiff and painful joints by 'Eau Courante' baths is being much advocated at the present time.

In this form of treatment the affected limb is immersed, usually, in hot water. The water is made to whirl round—as a kind of whirlpool arrangement—by means of a motor-driven propeller. In some of the 'Eau Courante' baths, air is also driven into the water under pressure.

The effect of this is pleasant, and produces hyperæmia of the part, and a sense of comfort. The effect of the air bubbles in the rapidly moving water produces a similar sensation to light massage.

This treatment is certainly beneficial and in slight cases will be all that is necessary if followed by exercises and use of the limb, but too much should not be claimed from its use.

A stiff and crippled joint can only be restored to functional utility by getting rid of the adhesions restricting mobility and rebuilding up the musculature.

These baths, just as the other physico-therapeutical methods, are of service, but cannot of themselves replace the main methods already described, and which are essential to successful treatment.

Application of heat immediately followed by massage is to be recommended in cases of stiff joints, but the main treatment—viz., the breaking down of the adhesions, either by forcible manipulation or gradual splintage, and the redevelopment of the atrophied muscles—is not lost sight of.

Ionization, too, is useful in some cases; it tends to loosen adherent scars, and assists very materially in promoting absorption of fluid in joints.

Like the other methods just referred to, it is useful in dealing with stiff and painful joints, probably in that it produces hyperæmia, which in this case lasts very considerably longer than when induced by other methods.

Ionization with chlorine or iodine ions is employed for resolving scar tissue, whilst for synovitis a 2 per cent. solution of sodium salicylate is the most effective.

Altogether too much has been claimed for ionization by some enthusiasts, but used with proper technique,—viz., long sittings and big currents—there is scope for its employment as an adjunct to the treatment of many of these cases of injury, either acute or chronic.

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