SOME NOTES ON OPERATIVE PROCEDURE IN NERVE INJURIES.

By ROBERT KENNEDY, GLASGOW.

IN operations for the restoration of damaged nerves there are many conditions which must be present before a successful result can be looked for. Where there is evidence of damage to a nerve trunk, and an open wound or a septic sinus exists, the first step is to get the wound or sinus healed by ordinary surgical treatment. After the part is healed completely, and a sufficient time has elapsed for the scar to be safely dealt with, the question of operation may be considered.

When the time for operation arrives, there are certain conditions which must be observed before a successful result may be prognosed. Thus, in the case of the nerve having been severed, it is necessary to find the two separate segments. These again must be healthy or undamaged by inflammatory processes, excepting in so far as the ends are affected by scar formation. The exposure of the nerve segments should be made above and below the seat of injury, in accordance with the anatomical indications. After the central and peripheral segments have been found, they should be traced downwards and upwards respectively towards the seat of injury. Any attempt to cut directly into the damaged part is apt to lead to a long and futile search for the nerve ends. Cutaneous scars over the seat of injury of the nerve should be removed if possible by joining the two incisions made above and below by an elliptical incision encircling the scar, so as to effect the removal of the cutaneous along with the underlying scar.

In the vast majority of cases both segments of the nerve trunks when exposed are found to have a greater diameter than the nerve when normal. Usually this need give no concern—the thickening is due to œdema of the nerve trunk, and does not appear to affect the result. Certain thickenings of the nerve are, however, of a different nature, and have a serious effect on the outlook. The nerve trunk may be found inflamed, appearing dusky-red with dilated vessels, and this condition is associated with pain of a very severe nature. In such cases the best treatment consists of incisions into the thickened and inflamed trunk, made in a longitudinal direction to avoid injury to the nerve fibres. Should the trunk have been extensively damaged, and be now found thickened with scar formation, the prospects of a satisfactory result are extremely bad. These cases, however, are very exceptional, and in the majority the two segments are all right except at the seat of section. As a rule there is practically no difference in the thickness of the central and peripheral trunks.

When the nerve ends have been dissected out, they may be found in various conditions. The severance may have been complete, with no reunion. Both ends may present bulbs, that on the central end being usually the larger. Both ends may be without bulbs, but terminate in tapering ends involved in scar. Sometimes the central end presents a bulb and the peripheral a tapering termination. Sometimes, again, a kind of reunion has been effected between the two ends; this may occur as a strand of much greater tenuity than the nerve, or it may present a swelling considerably thicker than the nerve. Sometimes two nerves in close approximation have been divided, and the ends have united in a cross—or more frequently one central end has become joined to the peripheral end of the other nerve, the two remaining ends being ununited. A nerve and tendon may have been simultaneously severed, and the central end of the nerve be found to have united firmly with the peripheral end of the tendon, or vice versa.

In order to test the conductivity of the nerve, an electrical interrupted current may now be applied to the exposed nerve trunk by a sterilizable electrode. The application should be made as soon as the nerve is exposed, before any manipulation of it has taken place, and may be repeated from time to time as different parts are brought into view. The presence of conductivity is shown by contraction of the muscles supplied by the nerve. When the entire distribution of the nerve trunk has been found to be affected before the operation, it is very seldom that the electrical stimuli produce any muscular contractions; but in certain cases where the trunk has only been partially damaged, or reunion has been partially effected, it may serve to show to what extent the nerve is conducting. The current, to begin with, should be the smallest necessary to evoke a contraction; and it will be found that the nerve trunk, when irritable, can be stimulated at different points in the circumference, with different contractions resulting, the fasciculi supplying different groups of muscles being thus capable of being separately stimulated by a current not strong enough to stimulate the entire trunk. Before being applied to the nerve, the electrode should be tested on an exposed muscle in the vicinity in order to see the amount of current passing.

Before dealing with the ends of the severed nerve, it is necessary to pay attention to the surroundings of the nerve trunk. If these consist of dense scar, the scar masses must be cut away so as to leave normal tissue for the sutured nerve to lie in. Any neglect of this will end in failure; and should it be impossible to leave the nerve in healthy surroundings, a bad prognosis should be given. The same applies in the case of a nerve damaged in a part which has dense surroundings naturally, being confined in a narrow space. The most frequently occurring example of this is the ulnar nerve, when damaged behind the elbow, where it is lodged behind the internal epicondyle in a sulcus having for its boundaries the internal epicondyle and the olecranon process of the ulna. In this case it is probably impossible to get a satisfactory result unless the nerve is dislodged entirely from its position behind the epicondyle and fixed in front of the epicondyle and under cover of the humeral origin of the flexor carpi ulnaris where it is not confined by bony surroundings. The reason is that the enlargement which forms at the seat of suture compresses itself against the rigid boundaries of the sulcus and thus prevents conductivity.

Where the loss of conductivity has been due, not to section, but to compression by cicatricial tissue or otherwise, attention must be directed entirely to the surroundings of the nerve, and on dissecting out the compressed trunk and ascertaining that it is intact, it only remains to dissect the cicatricial tissue away; the removal must be thoroughly done, otherwise recurrence of the compression will probably take place. When this is not possible for any reason, the prognosis is not good. In some cases the compression has been so severe that the nerve on removal of the scar shows a constriction over the entire extent of the compression; at other times the compressing ring has been so narrow that a furrow surrounding the nerve is all that shows the site of the compression on removal of the cicatrix. Should the perineurium be intact, such compression furrows or constriction do not call for excision, for the nerve will recover quite well. The constriction is not really so deep as it appears, owing to the oedematous condition of the nerve trunk above and below, which has not been under compression.

The next step is to determine the possibility of getting the segments to meet. This should be done before the nerve ends are prepared for suture, as otherwise the manipulation necessary to make them meet might so damage the freshly prepared ends as to endanger the result. At times they meet quite easily, but in other cases it is quite impossible to get them to do so. If the nerve has simply been shot through with a bullet, there is no difficulty; the ends may have retracted some distance, but this can be overcome. In other cases, however, such as shell wounds where a large piece of the nerve has been shot away, or where a septic condition has resulted in the sloughing of a large piece of the nerve, it may be impossible to bring the ends together.

If the ends do not come into apposition easily, various procedures may be adopted. Care should be taken, first of all, to see that the segments of the nerve trunk are not caught in a cicatrix further up, or down; this is often the cause of the difficulty in

making the ends meet, and when this cicatrix is cut, contact is easily made. Should this not be the cause, then see if relaxation of the nerve can be obtained by a movement of the joints above and below the seat of nerve section. In the sciatic, coaptation may be effected quite easily with the knee flexed, when separation by a considerable distance would be the result in the extended position; in such a case the nerve is sutured with the knee flexed, and the flexion position is maintained until the wound is healed, after which the limb is gradually extended and the nerve stretched without harm. This is also the case with the median and musculospiral in the arm by flexion of the elbow, and with the median and ulnar in the forearm by flexion of the wrist. Flexion or extension of the elbow has little effect on the ulnar in the arm. In the case of the median, ulnar, and musculospiral in the arm, adduction of the arm causes relaxation. This is not so noticeable in the musculospiral on the outer aspect of the arm, where the limb is adducted when the nerve is being exposed; but in the case of the median, ulnar, musculocutaneous, and musculospiral in its upper part, the limb may be postured for the operation in a position of abduction, even to a right angle; this should be remembered if any difficulty of approximation arises, as the operation can be finished with the limb adducted, and thereby great relaxation of the nerve trunks will be obtained. In all cases where the ends of a severed nerve are being approximated by means of flexion of a joint, it must be carefully kept in mind that no relaxation must be permitted until the wound is healed. The danger lies in an extension movement being inadvertently made by the assistant who is holding the limb in the flexed position; and it is necessary to watch that this is not done, or the nerve ends may thereby be torn asunder. When the brachial plexus is being dealt with above the clavicle, relaxation of the nerve trunks is brought about by raising the shoulder and abducting the head on the side of operation; this may enable a gap to be bridged and a suture to be tied; the position must, of course, be maintained by an appropriate splint throughout the healing of the wound.

In the event of the necessary relaxation not being thus attained, stretching of the nerve trunk should be tried; but this should not be done until it is ascertained that less forcible methods fail, as it is a good principle in all operations on the nerves to use as little force as possible, and to conduct every procedure with the utmost gentleness. But the ends must be induced to meet if possible.

In stretching the nerve trunk, the method of procedure is to grasp the nerve with a piece of gauze, and make steady traction, avoiding any sudden movement, and being most careful not to allow the grasp to slip along the nerve: this is harmful from the irritation which it causes by damaging the surface of the perineurium, with the further possibility of dense adhesions forming along the nerve trunk. If the traction is excessive, then rupture of the nerve fibres may occur, but it is astonishing how much traction can be borne without this accident. Any operator may satisfy himself on this point should he meet with a case where partial reunion has occurred in a motor or mixed nerve and some of the muscles have recovered a partial nerve-supply. Here the only satisfactory method of treatment is excision of the cicatricial segment and suture; but in certain of these cases the reuniting segment which requires excision is so long that stretching may be necessary to effect apposition. In such conditions the application of the electrode to the distal segment will show at certain points responses in the muscles, and these can be re-examined after each stretch. It will then be found that the ordinary stretching necessary to effect considerable elongation does not rupture the fibres, as the muscles continue to give their responses. This is just what might be expected from what we know of the condition of nerve fibres in severed nerves. If a portion of a nerve trunk is excised and prepared for microscopical examination, longitudinal sections always show the fibres to follow an undulating or zig-zag course; and if preparations are desired showing the nerve fibres running a straight course, it is necessary to put the portion of nerve on the stretch when it is fresh, and to keep it stretched while fixing. It is this undulating course of the fibres in a severed nerve which permits of so much stretching of the nerve trunk without rupture.

Stretching presents unusual difficulties in the case of the cords of the brachial plexus

above the clavicle. Many years ago, in dealing with cases of Duchenne's paralysis, which is due to rupture or cicatricial compression of the fifth and sixth cervical nerves at their junction in the plexus, I found this difficulty very great. These trunks are often fixed in a cicatrix over a considerable area, and it is necessary to work in a small space above the clavicle. Section of the clavicle would give freer access, but is a most undesirable complication of the operation. The nerve trunk, once exposed, has to be fixed while being cleared of cicatrix, and I found that when I fixed the scar with forceps while the nerve was being put on the stretch for clearing adhesions, the cicatrix became torn and finally ruptured,

FIG. 288.

after which the completion of the operation was difficult. I therefore devised a nerve stretcher which I have since found of great help in suitable cases—viz., those where the ends of the nerve are united in cicatrix which, while reuniting the ends, permits no efficient conductivity, and which must therefore be excised. The instrument, as shown in *Fig. 288*, consists of a piece of thin steel cut in the shape of a cross, each arm terminating in two prongs with bulbous ends. The breadths of the arms at their terminations measure respectively $\frac{1}{2}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in., and $\frac{5}{8}$ in. The prongs are intended to be placed astride the cicatrix, and on rotating the instrument, as shown in *Fig. 289*,

FIG. 289.

the nerve is efficiently put on the stretch with no damage to the nerve itself, only the cicatrix being pressed upon, and this is to be excised before suture, at the points A and B. On stretching the nerve, the adhesions are drawn taut, and fly asunder on being touched with the knife. At the same time the distal end of the nerve is drawn up into approximation with the central. The different spacing between the prongs adapts the instrument to different lengths of cicatrix, and the bulbous ends prevent the instrument from slipping once it has grasped the cicatrix.

Another procedure which may be adopted to effect approximation of the nerve ends is frequently applicable to the ulnar when wounded in the arm or forearm. This depends on the fact that the ulnar is very greatly relaxed when displaced from the sulcus to a position in front of the internal epicondyle of the humerus, and wide gaps between the nerve ends can thus be overcome. It is done by making an incision over the ulna at the elbow and dissecting an anterior flap forwards. The ulnar is then made to follow a course between the muscles arising from the internal epicondyle. This is sometimes done by dissecting out the distal end of the ulnar, when the lesion is in the arm, and passing it through between the muscles into the arm; in other cases by incising the humeral origin of the flexor carpi ulnaris, placing the nerve in position, and then suturing the muscle over the nerve.

Should the nerve ends only meet with difficulty, showing much strain, it is better to fix them not quite in contact, rather than that the ends should be overstrained. In such cases good results are obtainable in spite of the fact that the approximation has not been absolute.

But there are cases in which no possibility of any reunion can be entertained, so great is the distance between the ends. Here the question of implantation or of grafting will arise, both of them procedures fraught with difficulties. It has been proved that one nerve can take the place of another, and enable function to be carried on; but the result is never up to the normal standard and is inferior to that of reunion. It has been proved also

that a portion of nerve when excised and implanted under the skin in another part of the body is not absorbed, but remains as a piece of nerve. Two nerves like the median and ulnar, one only of which has suffered a considerable loss, may be taken as an example. The sound nerve may be incised transversely, to the extent of about a third of its thickness, at two points separated widely enough to permit the central and peripheral ends of the damaged nerve to be stitched in without tension. It is possible that the fasciculi cut may be mainly sensory fibres, but that should not matter, as they are merely wanted to connect the two ends of the damaged nerve, and ought to serve this purpose equally well whether sensory or motor. It would be different in the case of an anastomosis, say, between the damaged facial nerve and the sound spinal accessory nerve, for there the central end of the facial is not available, and therefore the entire spinal accessory must be cut across to give a share of all the motor fibres. The same would apply to the principle of anastomosis performed in any nerve. The objection to the method is the cutting across of sound nerve fibres; but this is necessary if the method is to have a chance. The plan advocated by some of making a longitudinal incision in the sound nerve is, of course, quite useless, as it sections very few—a quite negligible number—of sound nerve fibres, and consequently there is nothing available for the new supply.

In the event of complete section of the nerve, the next step in the operation is to 'freshen the ends' preparatory to suture. This term, which is frequently used, is apt to give rise to a misconception as to what is to be done. The word 'freshening' would indicate the removal of the surfaces in a wound so as to prepare the way for the union of fresh surfaces; but in the case of the ends of a nerve which has been divided and has not reunited, or which has reunited by a cicatrix which does not conduct nerve impulses, the freshening required is the removal of all new formation, whether neuroblastic or fibroblastic in origin. In all cases it is most essential to see the normal appearance of the fasciculi in the nerve section, and slice after slice must, if necessary, be cut from the nerve end until this is attained, not only in the central but also in the peripheral end. The appearance is usually typical—the fasciculi projecting out from the perineurium in the form of small cylindrical processes (*Fig. 290*). When this is seen, all is satisfactory as far as the nerve end is concerned. Sometimes, however, the appearance is slightly different, and the fasciculi appear larger, do not project beyond the surface, and have a glairy look; this is due to œdema, and is also quite satisfactory. Sometimes one is tempted to stop the slicing process before these appearances are seen, because of the difficulty in getting the two ends to meet; but the temptation must be resisted, for if nerve ends which have been inadequately prepared are united by suture, the result cannot be promising.

FIG. 290.

Bulbous ends are formed partly of cicatricial tissue and partly of young nerve fibres which have developed outside and beyond the old neurilemma sheaths, and are therefore disposed tortuously. It is not safe to reunite a nerve trunk by means of the bulbs; some result might be obtained in this way, but it is apt to be imperfect; the connective-tissue element in the bulb may contract and interfere with the conductivity. It is therefore right to remove the bulbs entirely.

Where a severed nerve is joined by means of a cicatricial segment blocking the passage of impulses completely or incompletely, it must be cut out, the exact point of excision above and below being determined by the slicing process until the fasciculi are exposed.

Having prepared the ends, the next question is how best to suture them, and what material to use. Since it is necessary to leave some foreign matter at the seat of reunion in the form of a suture, the important points are to use the material which will cause the least irritation, and to use the smallest possible quantity of it. The idea of enclosing the ends in a membrane to prevent interference with the process of regeneration from the surrounding fibroblasts is not new, having been employed by Vanlair many years ago; more recently Cargile membrane has been largely used for this purpose. The great objection, however, to such procedures is that the foreign material left at the seat

of suture is considerable, and requires either to be absorbed or encapsuled; both of these processes are accompanied by considerable reaction, and this may result in new formation of connective tissue which may prevent the desired result by its contraction.

Numerous or too thick sutures are objectionable for the same reason, and are quite unnecessary. The nerve ends can be quite sufficiently coapted by a single fine suture,

FIG. 291.

passed once through each end, and tied not too tightly, but sufficiently to hold the two surfaces in apposition (*Fig. 291*). The other method is that of suturing the perineurium only, several sutures being placed round the nerve so as to coapt the two ends exactly without passing through the portion of the trunk transmitting the nerve fibres. The objections to the perineural suture are that more material is left at the seat of suture, and that although the periphery is closely coapted, the two surfaces bounded by it are not so well held together as with a through-and-through stitch, and may be separated by blood-clot as shown in *Fig. 292*.

FIG. 292.

The amount of damage to the nerve fibres caused by a single through-and-through stitch is very trivial, and can be reduced to a minimum by the use of the special needle represented in *Figs. 293, 294*. This needle is curved, and to the extent of one third of

FIGS. 293, 294.

its length from the point is flattened from side to side with a cutting edge on concavity and on convexity. About one third of its length from the point the needle gradually increases in breadth so as to permit the eye to be made in the same plane as the two cutting edges. Many needles have the eye passing in the opposite direction to the cutting edges, and this makes a great difference in the amount of damage which the thread inflicts on the nerve during the passage of the threaded eye. The nerve is transfixed as shown in *Fig. 294*. The flat needle cannot wound many

fibres in its passage, and the loop of suture is so placed, owing to the direction of the eye, that it easily takes the slit made by the needle.

The thread employed in the suture may be absorbable, or one which requires to be encapsuled. If the former, then the finest catgut should be chosen, and prepared by some method which renders it sterile and absorbable in fourteen days. I have always employed, except in experimental work on small animals, chromicized catgut, specially prepared for this purpose by my staff.* In the case of extremely fine nerves in experimental work on monkeys, where the finest catgut would be relatively too thick for suture of the nerve without causing too much damage, I have used horsehair, and found it very successful. The nerves reunited functionally, and at the physiological examination the horsehair was found encapsuled at the seat of suture. It is a perfectly safe suture, and could well be used instead of catgut in any case.

There now only remain a few general considerations. Nerve regeneration, whatever be its nature, finds without any doubt the greatest bar to its successful accomplishment in the development of the fibroblasts into fibrous tissue. This has not only an antagonistic effect on the process of regeneration, but a destroying effect after that process is accom-

* The raw catgut is loosely wound on reels made of glass rods bent into rectangles, one piece only being put on each reel so as to allow the different liquids free access to the gut. On these reels it is soaked in ether for twenty-four hours to remove fat, and then dried in air. It is now soaked in 0.1 per cent aqueous solution of chromic acid for three days, and then washed in running water for two or three hours to remove all unfixed chromic acid. It is next boiled in alcohol in an open glass tube for one hour—not with any intention of sterilizing, but so as to dislodge all the air-bubbles from the interior of the gut thread—and then allowed to cool in the alcohol. It is these air-bubbles which make catgut so difficult to sterilize, as they prevent the antiseptic from getting access to the organisms in the portion of the gut lodging the air-bubble. The gut is finally soaked in 20 per cent carbolic glycerin for a few days, and preserved in the same fluid till required for use. Before use, the antiseptic is removed by soaking the gut in alcohol.

plished. In operative work, therefore, everything which tends to produce scar formation militates against success. Aseptic technique of a high standard is essential if good results are to be expected. It is no proof to the contrary if a case of nerve suture has become septic and yet a good result has followed: it will certainly be a very exceptional occurrence. Therefore the greatest care to prevent the entrance of organisms into the wound is a rule the importance of which cannot be overestimated, in order to leave as little sterilization work to be done by the tissues as possible, and thus require the minimum of reaction in the wound. It is true that many cases of subcutaneous rupture of nerves are met with in which no recovery of function takes place, although no bacteria have been at work at the seat of rupture; but in these cases the failure to unite functionally is due to the same cause—namely, the intensity of the reaction, leading to the formation of connective tissue which contracts and prevents conductivity in any nerve fibres which may have regenerated. This reaction is not due to micro-organisms, but to the trauma which caused the rupture and the processes which follow thereon.

For the same reason it is essential that all manipulations of the nerve throughout the operation should be of the gentlest. The knives should be as sharp as possible, all nerve slicing should be done with a fresh knife which has not been used since it was sharpened, and the slicing should be performed with a gentle sawing movement so that the fibres sustain as little damage as possible. The less force required to effect all the procedures, the more likely is there to be a good result. This is the chief reason why it is desirable to use a tourniquet, applied after the limb has been emptied of blood as completely as possible, so that the procedure shall be bloodless. The bleeding is often considerable in these cases, particularly if there has been much scar formation, and the constant swabbing which is required to keep the parts clear, and the application of hæmostatic forceps and ligatures, must considerably irritate the parts in which the newly-sutured nerve is to lie. If the limb is properly emptied of blood, the whole procedure may be carried out in a much shorter time; and there is no need for swabbing, and consequently much less trauma. Before the suture is completed, if there is any chance of damage having been done to a vessel of any size, the tourniquet may be removed, the vessels ligated if necessary, and then the nerve operation completed and the wound closed; but in the absence of this exceptional circumstance, the best way is to close the wound, apply the dressing firmly, and then remove the tourniquet. Any blood that oozes from the capillaries escapes into the dressings and does no harm, and it is a very rare circumstance for there to appear more than sufficient to stain the innermost dressing.