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Peripheral nerves surgery

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PERIPHERAL NERVE SURGERY

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Table of Contents

INTRODUCTION

The incidence of peripheral nerve injury always looms high during war, so on December 7, 1941, the need for better surgical technics in caring for these injuries began to become very apparent. To devise and to institute better surgical technics, the surgeon needs to know the basic factors influencing successful nerve regeneration.

The purpose of this paper is to review the factors which influence regeneration so that the reader can better evaluate those technics and materials already in use and those which will be introduced from time to time.

The field of peripheral nerve surgery is so broad that discussion of all phases is not attempted here;, instead, this paper is confined to consideration of repair of nerves which are known to have been severed. The problem of differentiating between and treating anatomical and physiological breaks in nerves is not considered

A very brief review of basic anatomy of nerves and regeneration of nerves is included for the convenience of the reader.

Anatomy of Nerves

The unit of structure in the nervous system is the nerve cell or neuron which consists of a body or perikaryon and two types of processes, one or more dendrites and a single axon. The cell body lies within the gray matter of the central nervous system or in outlying ganglia, and the axons make up the peripheral nerve network.

Within the gray matter axons and dendrites are simple protoplasmic extensions of the cell body but in the white matter they are invested by a sheath of lipoid material called myelin. In peripheral nerves the myelin sheath is encased by a nucleated membrane , the neurilemma or sheath of Schwann. In the peripheral nerves at regular intervals, the myelin sheath is interrupted and the neurilemma dips into the gap; these evenly spaced constrictions are the nodes of Ranvier. The myelin sheath is lost near the termination of the nerve fiber and distal to this point the neurilemma discontinues and the fibers terminate as naked axis cylinders.

Degeneration and Regeneration

The processes of nerve degeneration and regeneration have been subjects of dispute since before the time of Waller and the modern theories are still not accepted without question by all investigators. It is not the purpose of the paper to present a detailed description of degeneration and regeneration nor to review the varios disputed ideas; rather, its purpose is to refresh the reader's mind so that he can better understand the problems of surgical nerve repair.

Waller first recognized the nature of degenerative and regenerative processes in nerves. His paper written in 1852 described changes in the peripheral segment of a severed nerve and these changes are still known as Wallerian degeneration in which the axon near the injury begins to decompose within a few days and by the third or fourth day the entire axon is involved and is completely lost by the fourth week. At the same time the myelin begins to degenerate into droplets of kephalin and lecithin which disappear around the tenth week. Subsequently the connective tissue and Schwann cells remove the degenerative products and the empty neurilemma tube alone remains.

Although Waller failed to recognized any changes in the proximal stump, changes similar to those he described have since been noted and generally accepted. (Cajal 1928). The extent of retrograde degeneration has not been settled, and there are many beliefs concerning the matter. Engelmann believed these changes stopped at the first node of Ranvier and Ranvier, himself, believed they could go back two nodes. Other investigators advanced varying opinions. Ranson(1912) pointed out that changes in the proximal stump may extend for varying distances, probably not over two cm. but the intensity of the degeneration decreases centrally and the exact point of cessation of changes is not discernible. In a good review of the subject, Young (1943) discusses death of some neuron cell bodies in the central nervous system as a result of axon injury.

Once degeneration is complete, evidence of regeneration can be seen in the advance of axon tips back down the neurilemma tube of the proximal stump, bridging the gap between the severed ends and extending down the tubes of the distal stump. Ranson (1912) noted that these growing axon tips divided to increase the number of fibers in the terminal part of the proximal stump.

Whether the advancing tips are semisolid axoplam (Young 1943) or fibrillar structures (Cajal 1928) is relatively unimportant; however, the fact that the neuron is capable of replacing distal parts of lost neurons is the basic feature of regeneration. If the advancing axon crosses the gap between proximal and distal fragments, it proceeds down the empty peripheral tubes to the end organs where it may or may not become functional. More will said of the feature further on in the paper.

Regeneration is not a single process nor a simple one. Young (1942) emphasizes that regeneration includes more than the re-entrance of axons into the old tubes and is not complete until function of the parts supplied by the nerve is restored. He divides the process into eight stages which are as follows:

1. Closure of the gap between the severed stumps, mainly by the outgrowth of Schwann cells from the peripheral.
2. Retrograde degeneration of the cut eentral ends of the nerve fibers, and the sending out of many fine branches.
3. The progress of the tips of the axons from the the central stump across the scar to the peripheral stump.
4. Break-up of the axon and myelin in the peripheral stump and removal of their remains by macrophages.
5. Multiplication of the nuclei of the Schwann cells and increase in the volume of their cytoplasm to

make Schwann-bands which eventually fill old sheaths.

6. Progress of axon tips along peripheral stump, spinning out new fibers behind them.
7. The arrival of the growing tips at endorgans and making of an union with it. This union may at first be atypical, and we should include here the subsequent process of normalization.
8. The increase in diameter of the fibers originally laid down their medullation.

The rate of regeneration has been another source of disagreement; but, as Gutmann et al (1942) point out varying methods of estimating rate have been used resulting in varied estimates. For example, since function does not return so rapidly as does the anatomical axonal structure, measurements by function and by histo logical studies of axons tips differ. This difference is clearly evident in a report by Young (1943) which records axon advancement in rabbits at 3.5 mm. per day while functional return is 2.6 mm. per day. Young also believes that the rate of regeneration is not constant but varies within the neurilemma tube.and at the scar.

Obviously functional recovery is the most important factor to a patient and Gutmann (1942) records this rate as 2.0 mm. per day after a nerve has been sutured. The following table from Groff and Houtz (1945) transforms the elusive figure of mm. per day to time elements more meaningful to both the patient and to the clinician:

Nerve injured	Time in months for signs of recovery
Radial	
M/3 humerus	7-8
L/3 humerus	6-7
Ulnar	
Wrist	5-7
Elbow	10-12
Axilla	15-16
Median	
Wrist	4-5
Elbow	8-9
Axilla	12-14
Sciatic	
M/3 thigh	10-12
L/3 thigh	12-14
Peroneal	
Head of Fibula	8-9
Popliteal Space	10-12
Tibial	
Popliteal Space	11-12

Why regenerating axons grow down neurilemma tubes toward the periphery has never been explained satisfactorily, but several theories have been advanced. Cajal (1928) first suggested that the peripheral stump exhibited a chemical attraction for the new axonal fibers, and later this chemical attraction or chemotropic factor was attributed to Schwann cell degeneration; however, experiment to prove the point have been indecisive.

Weiss (1943c) concludes that fibers will not grow into homogenous media but advance only along interfaces or surfaces and are guided by biophysicalforces of these interfaces rather than by biochemical forces while Young, Holmes, and Sanders (1940) are inclined to believe as did Huber (1895) that the young fibers, when they come into contact with a solid surface, follow a course of least resistence in which case the entrance of fibers in the tubes is merely a matter of chance.

Regardless of which theory is correct, one can easily realize that the shorter the gap between severed stumps, the more effective is the distal segment influence, tropic or mechanical; therefore in peripheral nerve surgery, close apposition of separated nerve ends is essential for good functional results.

The problem of fibers reaching appropriate end organs is interesting since most effective connections are made by similar fibers; e.i. the new fiber should be similar to the degenerated fiber which previously occupied the tube, sensory for sensory and motor for motor. (Weiss 1945, Young 1942). Weiss found that dissimilar fibers could reinnervate end organs but that such endings were largely atypical; and Young (1943) discovered that the axon can flow out of the tube along the muscle and establish a new end plate; however this process is slow and the new connections are not normal.

Seddon (1943) presents a clear view of the end organ problem; " fibers of one kind may grow into tubes leading to end organ of another kind; or a fibre may grow into a Schwann tube of the proper kind, but leading to a destination different from the one originally served by that particular fibre. In the first place the new axon is wasted; and in the second, it is functionally misdirected."

Stookey (1922) admits that sensory roots can grow into motor end organs but reminds one that functional regeneration has not followed.

Whether these studies as a whole are accepted or rejected is not too important; but, since there is a very good probability that fibers should be rerouted down appropriate channels, it seems wise that nerve ends not be rotated on each other so that the chances of correct routing are maximum. Further application of the principle that each fiber is predestined for certain function is seen in nerve crossing operations as used in repair of facial palsy which is discussed later.

Factors of Regeneration

Success in peripheral nerve surger is attained only when function of the part is regained and this success is dependent upon establishment of conditions which permit descent, growth and medullation of axons from the proximal stump through the sidtal stump to appropriate end organs. Any factor which alter the course or maturation of the axon should be eliminated whenever possible. Let us, then, consider factors which influence regeneration. The first two to be considered are those given by Spurling (1943) as the two cardinal principles of surgical technic.

1. Freedom of tension at the suture line

Undue tension at the suture line may cause separation of nerve ends destroying continuity of neurilemma tubes and increasing opportunities for descending axon tips to wander into inappropriate tubes and into surrounding tissues. Severe tension, even when the suture line holds, may result in nerve cell death and degeneration of entire nerve, the rupture of fibers, or reduction of blood supply. (Groff and Houtz 1945). Perfect hemostasis of the nerve bed decreases ultimate fibrosis which is excessive might constrict down around the nerve and promote secondary degeneration.

Several procedures are used to obtain freedom of tension and choice of these methods depends on the nature of injury and circumstances. Spurling (1943) gave three methods, namely, grafting and splicing procedures to bridge a gap between retracted nerve ends; positioning of the extremity in flexion or extension to give shortest normal anatomical course; and rerouting of the nerve along a new, short course following dissection of nerve ends from the natural bed.

Relaxation of the nerve by temporary positioning of joints can be maintained by posterior shell or cast in complete immobilization for two weeks and then gradual extension to stretch the nerve by the sixth week post operative. (Spurling 1943). Mercer mentions several good examples of appropriate use of the procedure and the extent of relaxation is rather remarkable. Flexion of the elbow to facilitate suture of nerves in the antecubital fossa may correct as much as a two inch retraction. Flexion of the wrist gives an extra inch to the median and ulnar nerves; while adduction of arm at the shoulder shortens axillary nerves an inch.

Mercer also gives several good examples of alteration in the course of nerves; the ulnar nerve may be transposed to the volar side of the medial condyle; the radial may be transferred to the front of the arm; and the median brought in front of the forearm flexor muscles. Spurling (1943) indicates that he has stripped as much as eighteen inches of the central stump from its normal bed and has achieved good results.

Although Mercer (1936) frowns upon bone shortening to bring retracted nerve ends into opposition, Schwartz and Parker (1945) described a case in which the humerus was shortened to permit radial nerve repair without complicating the patient's recovery; however, the authors did not have a report on functional return as there had not been sufficient time for regeneration. White osteotomy seems to be a radical procedure, it may make possible the direct sutuing of nerves and subsequent return of function which might, otherwise, be impossible; therefore, the surgeon must weigh the risk against importance of function and possibilities of a successful nerve graft.

2. Perfect hemostasis of nerve ends

Hemostasis of the nerve ends is essential because any accumulation of blood between the ends imposes an initial sparation of neurilemma tubes by a homogenous media through which axons have difficulty passing (Young, Holmes and Sanders 1940) and a secondary scar through which fibers can not penetrate and which leads to constriction of the nerve as the connective tissue matures.

In Spurling's (1943) discussion of obtaining perfect hemostasis, he suggested that the operator trim the central stump until nerve fibers and well formed tubes are seen and, then, stop the inevitable bleeding by holding a thin strip of muscle over each cut end with gentle pressure. After three or four minutes a gentle stream of normal saline directed at the muscle implant and nerve end junction will permit removal of the implant without reopening the bleeding points. Huber (1920) suggested using moist cotton to control bleeding. During these procedure and any other procedures it is well to keep in mind the advice of Sachs (1920) and to remember to handle the nerve carefully. He suggests keeping the nerve ends wrapped in hot cotton during all procedures which are time consuming so that tissues will remain viable.

3. Scarring

As already mentioned, scarring at the site must be held at a minimum. Since any intratubal scarring will block descending axon tips and since traumatization followed by scarring of the nerve ends is inevitable in use of needles and sutures (Klemme et al) various means of reducing scarring have been tried. Studies have been directed along two lines, first, search for a suture material which would not incite excessive connective tissue response, and, second, experimentation in methods of maintaining nerve end apposition without actual sutures.

After 400 years of searching, we have finally found a metal suture material which is practically inert. Vitallium and tantalum both are almost inert in the body and are not affected by metabolic reactions; however, vitallium is a hard alloy and has to be cast while tantalum is a malleable and ductile element; therefore, tantalum is more useful. (Spurling 1943). Pudenz (1942) and White and Hamlin (1943) studied the effects of tantalum and reported that it incites little connective tissue overgrowth and scarring is minumal compared with other suture materials.

White and Hamlin (1943) offer two more arguments in favor of tantalum; it is easy to tie as the first half of the square knot does not tend to slip; and, since the wire breaks under "unnecessary tension" it offers further protection.

As a possible fourth asset ascribed to tantalum is its radiographic opacity. Spurling (1943) uses sutures and foil so that post operative x-rays will show separation of suture line or bulging at the suture line indicating neuroma formation before clinical signs would indicate something amiss.

These same authors restrict their suturing to the epineurium rather than extending into the nerve substance itself as suggested by Stookey (1922); thus further reducing intratubal scarring; however, a certain amount of scarring is inevitable whenever sutures are used and the search for a sutureless technic is maintained.

In 1940 Young and Medawar introduced the use of fibrin or plasma which they poured around the nerve while holding the ends together. Little or no plasma penetrated between the nerve ends and histological studies were favorable. Seddon and Medawar (1942) reported that plasma was good in primary sutures and was especially useful in grafting. Micheal and Abbott

(1943) studied tissue reactions and found little and considered its use as "promising". Tarlov and Benjamin (1943) favor autologous plasma clot because of less inflammation and describe a rubber mold to hold the clot around the nerve; also they note that this material will not take any tension. If the nerve is under tension, the plasma clot is useless; therefore, suture is required. (Rezende 1942).

Singer (1945) offers a solution to the last mentioned problem of tensile strength of plasma clot in using the clot in conjunction with a fibrin film wrapped around the nerve at the site of the suture. As the plasma dries, the film is bound to the nerve and tension along the nerve is transmitted to the film. Although the film is absorbed rather rapidly, tensile strength is maintained by the nerve itself, presumably by out growth of Schwann cells. Histological studies show that the nerve fibers are not all properly alligned in the longitudinal axis; however, the author was favorably impressed, although he will admit that fibrotic reaction to the film indicates an improvement could be made.

Ferry and Morrison (1944) report that it is possible to modify the susceptibilitiy of fibrin products to attack by proteolytic enzymes and prolong their rate of absorption hence their period of effectiveness.

Plasma clot has found use in preparation of cable grafts making them easier to handle (Young, Holmes and Sanders 1940) and giving best union (Tarlov and Epstein 1945). After comparing plasma clot with gum acacia, Rezende (1942) concluded acacia is better. Klemme et al (1943) reported favorably on use of acacia glue and noted the glue may be autoclaved without deleterious effects.

Another sutureless technic is described by Weiss (1943 a-b) and Weiss and Taylor (1943), the arterial sleeve. In this procedure of reapproximating nerve ends,a segment of artery is fitted over the line of apposition by an instrument devised by Dr. Weiss. Fresh and frozen-dried segments have been used with similar results except the later seem to "absorb" a certain number of regenerating fibers. Heteroplastic sleeves provoked heavier adhesions than homoplastic cuffs. When other means of preservation of the sleeves were tried, the sleeve was transformed into a foreign body with more tissue response.

Several dangers arise in these sutureless technics;

one being, failure os establishing and maintaining accurate apposition of nerve ends with introduction of homogenous media between the ends and subsequent failure of axons to bridge the gap, and another being, introduction around the nerve of a material which may evoke a tissue response which will strangle the nerve and defeat the main purpose of using a sutureless method, namely, to prevent scarring.

Any procedure which results in scarring is to be avoided because of an impairment of a growth factor reported by Weiss and Taylor (1944) after they studied results of constriction. They discovered that the central body continuously contributes to the growing fiber and constriction of the nerve throttled such contributions and reduced growth and myelinization, hence, impaired functional recovery.

4. Blood Supply

The problem of scarring brings up another problem which is directly related to scarring, that of blood supply. It is fundamental that the nerve maintain an adequate blood supply so that the tissues may remain viable or fibrosis with scarring results; therefore, it is logical to assume that anything which decreases blood supply is to be avoided in either direct suturing or in grafting procedures.

Tarlov and Epstein (1945) made an interesting report on the importance of an adequate blood supply in nerve grafts. They demonstrated, visually, the pattern of blood vessels in nerve grafts and concluded that vessels from surrounding tissues, entering at right angles to the nerve, are larger and more important than those entering at the ends of the graft; however, they admitted that demonstration of the small capillaries coming in from the ends is difficult and that they play an important role in vascularization of grafts. Although their report is confined to studies of vascularization of nerve grafts and offers no comparison of relative importance of the two blood supply routes in direct end-to-end anastomosis, we may assume that, if perpendicular blood vessels are more important in grafts, they are at least worthy of consideration in direct anastomosis as well. We can not carry our assumptions too far, however, inview of a report by Spurling (1943) in which he states that the more important vascular channels lie parallel to the nerve. Until conclusive evidence is presented, the question of relative importance of these blood channels is unsettled and we must consider both in nerve surgery;

therefore, use of arterial sleeves for suture and wrapping of suture line with sheaths, membranes and foils is not to be accepted without caution as they tend to decrease ingrowth of capillaries from surrounding tissues.

In the same report by Tarlov and Epstein (1945), they discredit attempts to increase vascularization by use of collodion tubes to prepare a bed of granulation tissue for nerve grafts, use of pedicle flaps of fatty areolar or muscle tissue applied to grafts, and tunelling grafts through muscle; but they approve of massage, heat and exercise to increase vascularization. Klemme et al (1943) warn that massage and motion should not be started before the second week and believe gentle electrical stimulation is beneficial.

As already mentioned, tension of the nerve will decrease the blood supply and result in intraneural fibrosis and subsequent blocking of axon descent.

It should also be mentioned that, while Tarlov and Epstein do not favor tunelling a graft through muscle to increase vascularization, many other investigators prefer to place a sutured nerve or grafted nerve in a new muscle bed to provide a smooth, bloodless field for minimal perineural scarring. (Gurdjian and Smathers 1945; Mercer 1936; Groff and Houtz 1945).

5. Time of Suture

The question of ideal time for suturing a divided nerve arises with conditions of the injury not with mere existence of a severed nerve, as it has long been realized that immediate suture of the ends after severing is ideal whenever possible because delay interposes inevitable changes which reduce the degree of recovery.

Changes in the proximal stump following injury and during delay apparently are minor as far as affecting regenerative powers. According Young (1942) the power of the central stump to send out fibers is not reduced provided it is severed a second time before suturing. One must remember that regeneration from the proximal stump begins within a few days after severance regardless of whether appropriate neurilemma tubes are available to guide axon downgrowth, and, if adequate connections are not made, axons will penetrate into surrounding tissues and form a bulb known as a neuroma which may be painful. (Young 1922). As one would expect, this neuroma has to be removed before nerve anastomosis can be accomplished, and this excision of the neuroma results in some loss of nerve substance and widening of the gap between nerve ends;

hence, neuroma formation constitutes one deleterious effect of delay in suturing.

The peripheral stump undergoes changes which actually reduce the ability of the stump to receive fibers. Stopford (1920) believed a delay of twelve to eighteen months, provided there was no infection, did not change the chances of recovery; but he did think that longer delays impaired results. Stookey in 1922 pointed out that after long periods of delay changes within the stump itself diminished chances for complete recovery of function. These changes in the peripheral stump are of two types according to Holmes and Young (1942); first, Schwann cells of the peripheral stump begin to lose their ability to put out new Schwann cells two to three weeks after the injury and after one hundred days the output may be very unsatisfactory; and second, tubal diameters reduce to about one-half their original diameter decreasing ability of the stump to receive fibers and to allow subsequent medullation necessary for complete return of function of a fiber.

If cut nerves are not reapproximated immediately, they will retract increasing the gap, and this retraction should be prevented if immediate suture of the nerve is not possible. (Mercer 1936). Mercer suggests suturing of the nerve regardless of the contraindication of sepsis because in this manner nerve ends can not retract even if regeneration does not proceed. Scarff (1945) suggests drawing free ends of the nerve together temporarily at debridement as do White and Hamlin (1943) who prefer to use tantalum to mark severed nerve ends and to secure them because tantalum allows radiographic visualization of nerve end position and provides a good method for finding the ends at surgery. One end of the "stay" tie of tantalum is left long and brought to the subcutaneous tissue where it is easily palpated after initial skin incision and can be traced to the site of nerve ends. Scarff (1945) points out that tantalum will not remain as infected foreign matter as will silk.

Another effect of delayed suture is pointed out by Stookey (1920). End organs may change during the delay so that they can not receive new fibers as already discussed previously. Atrophy of muscle makes attempts to reinnervate them useless since no motor function can return. We do have methods of determining whether atrophy is complete and Duel (1934) suggests that repair be attempted in any case in which muscle response to galvanic stumuli indicates the muscle has not undergone too much fibrous atrophy. Although Violé (1944) warns that electric stimuli tests are not without some error, it is well to remember such tests and to follow reports of investigation in evaluating them.

Since studies tend to prove that delay in suturing decreases changes for maximum recovery of function, what factors constitute contraindications for suturing? The extent of accompanying soft tissue damage and the circumstances in which the injury is acquired and conditions prevailing in place where surgery is conducted may justify delay.

Severe, penetrating or crushing wounds commonly encountered in war may necessitate delay for the following reasons according to Scarff (1945): in the first place, evaluation of extent of damage is confusing since demarcation between viable and non-viable nerve tissue is not definite; in the second place, wide defect in the nerve necessitates "mobilization" of the nerve which requires wider exposure than is safe in grossly contaminated and potentially infected wounds. Third, such mobilization requires more time than is usually available because of the patient's general condition or because of "the exigencies of the situation". Finally, battle wounds with soft tissue damage are best left unsutured for five to ten days and during this time nerve sutures invariably break down.

In such instances debridement is the best treatment and at this time the nerve ends should be drawn together to prevent retraction as discussed previously. Scarff (1945) believes that definitive suture of nerve should be accomplished four to five weeks after secondary closure of the wound at which time the nerve is considered to lie in a sterile field, and Schwartz and Parker (1945) in their orthopedic war wounds found that orthopedic surgery should be done first and neurosurgery in three or more weeks.

Davis and Livingston (1945) believe that end-to-end anastomosis should be accomplished within the first three weeks except in severe, fulminating infection; while Loyal Davis (1945) states that fear of infection in the wound should not be used as a reason to delay apposition of nerve ends because infection does not always prevent regeneration but does so only if the infection is in the nerve fasicles themselves. Klemme et al (1943) believe that in a majority of cases, the wound can be changed from contaminated clean if seen within three hours of injury and primary suture of the wound may be effected.

It is well established that sulfonamide drugs are of definite advantage in treating these infected wounds and do not prevent neurotization of the stump. Use of the sulfas locally is advocated by Davis et al (1944) while Scarff (1945) indicates that systemic use of sulfadiazine offers protection against sepsis and eliminates scar formation incited be local sulfonamide.

6. Miscellaneous Factors

There are a few other factors which may influence regeneration and final restoration of function and which deserve mention although full discussion is not possible in this paper.

Although rotation of the nerve stump on themselves has already been discussed as detrimental in establishment of nerve endings, it is wise to mention it again here as a factor influencing recovery of function. To prevent rotation most surgeons are using two fine silk sutures, one in each stump, in the epineurium as guides to proper allignment during final suturing.

The nerve injured influences recovery of function. In view of the discussion of the chance that appropriate fibers ultimately will reach proper end organs, one can realize that a pure motor or pure sensory nerve has better chances than a mixed nerve in which some fibers will enter the wrong neurilemma tubes. Groff and Houtz (1945) state that ulnar and radial nerves regain function with greater consistency and completeness than do the median and sciatic nerves for this reason.

An early belief that the site or level of suture influenced recovery, with prognosis being better when the level is nearer the spinal cord (Stopford 1920), has to be forsaken or even reversed when one considers, first, that with a lesion nearer the central nervous system, retrograde degeneration will result in death of more neuron bodies resulting in fewer fibers regenerating than would were the lesion lower (see discussion of retrograde degeneration), and second, that regenerating fibers from high lesions have greater distances to traverse allowing the most distal portions of the peripheral stump and the end organs time to undergo changes which prevent complete recovery and allowing time for muscle atrophy (see discussion of effects of delayed suture)

As in any type of surgery, the state of health and general condition of the patient influences nutrition supplied to structures involved and, therefore is a factor in extent or degree of recovery. (Groff and Houtz 1945).

Violé (1944) indicates that age is a factor in rapidity of repair.

Several references have already been made to value of pre- and post operative care, such as debridement; electrical stimulation to prevent muscle atrophy during reinnervation period; heat, massage, and exercise to stimulate vascularization; and gradual extension of joints flexed to lengthen nerve routes.

Further Consideration of Nerve Grafting and Splicing

As has already been stated, direct end-to-end anastomosis of severed nerve ends is preferred; however, when nerve substance is lost and the nerve ends are retracted beyond control by other methods discussed, direct anastomosis becomes impossible and the problem of nerve grafts to bridge the gap arises. (Huber 1920). Other material have been used in an attempt to bridge the gap also.

Let us first consider procedures and materials other than nerve segments for use in bridging defects. Platt and Bristow (1924) discredit neuroplasty, i.e. the bridging of a gap by turning down a flap from the proximal to the distal nerve stump, or vice versa, as being illogical and futile. They also contend that tubulization with fascia, blood vessels, or some foreign material is without value. Stookey (1922) tells of bridging the gap with cables of cat gut without success.

Acceptance of these methods as useless is almost general; however, Weiss (1943c) has shown some success by a method which resembles tubulization. In his experiment he used arterial sleeves to hold nerve ends together leaving a small gap between the ends as they lay within the arterial tube, and he reports his results from functional standpoint as "optimal". Since Weiss also stated in the same article that nerve fibers will not grow into homogenous media, it is difficult at first to rationalize his technic and evident success; however, he attributes the success to the fact that the clotted blood which fills the gap undergoes changes which provide surfaces and interfaces along which the axon may advance.

"Within three days, the clot uniting the nerve ends gives way to a system of longitudinally directed connective tissue fibers establishing straight parallel bridges between the stumps. This is achieved by the fibrinolytic action of a nerve exudate, presumably normal endoneurial fluid, which liquifies all parts of the clot no under longitudinal stress."

Apparently the function of any material used to bridge a gap in nerves to a large extent is to provide the mechanical element of surfaces or channels through which axons may grow. (Rezende 1942). Since a nerve graft presents thousands of microscopic channels, it would seem that grafts should give better results; at least good results have been reported.

A number of kinds of nerve grafts have been used and are defined by Huber (1920). Autografts are those from the individual who is to receive the graft; homografts ar those from a different individual of the same species; and heterografts are those from an individual of a different species. Any of these grafts may be used after preservation or fresh as pre-degenerated or undegenerated and as single or cable grafts.

Reports of experiments in which various grafts were used are somewhat confusing and the reader is left confused as to which grafts yield best results.

Heterografts have usually met with poor results and their use seems questionable. Huber (1920) in a comparative study found heterograft yielded less certain and less satisfactory outcomes and the require more time. He noted that many of the down growing axons passed outside the graft and thus reached the distal stump. Weiss and Taylor (1943) point out that heterografts are largely discredited and Weiss (1943b) states that success is negligible. Tarlov and Epstein (1945) agree that heterografts are not good materials to use in bridging nerve defects.

Autografts have been more successful (Huber 1920). Young et al (1940) report that fresh autografts are almost as good as normal peripheral stumps, and Violé (1944) states that autografts are best. Weiss and Taylor (1943) believe autografts are good but point out that their use is self-limited because of unavailability of the grafts without sacrifice of some other nerve. The seriousness of the sacrifice may be altered by using cable grafts (Tarlov and Epstein 1945). Huber (1920) suggested use of cutaneous radial, musculo cutaneous and crural nerves for cable grafts.

Homografts are used the most because the are more available than autografts and give results which are better than heterografts. (Tarlov and Epstein 1945).

Conflicting opinions as to the value of pre-degenerating a graft before use are found in the literature. Sullivan (1936) says degenerated grafts are best, while Young et al (1940) state that pre-degeneration is of no value. Huber (1920) thought that, since any transplant used underwent degeneration before regeneration, transplants already in the process of degeneration would be most valuable; however, his experiments did not support his hypothesis and no difference was evident.

Cable grafts, whether autogenous or homogenous, have an advantage when the nerve being repaired is thick and when a single thick graft would not be easily and quickly vascularized. Tarlov and Epstein (1945) prefer cable to single graft in such instances and use plasma at the extremities of the graft to allow easy handling and good apposition. After the graft is in place, they spread the strands of the cable in the tissue bed to increase vascularization.

Source of grafts and preservation until time of use offers another problem in homografts. Cadavers are the obvious source although Lam (1943) suggests use of nerve material from limbs amputated for dry gangrene or other non-infected lesions to obviate necessity of begging pathologists for tissues and to avoid any medicolegal problems. Even then, one realizes that nerve material might not be available at the time of emergency surgery, so need of preservation is evident; however, discussion of methods of preservation is not possible in this paper. The basic factor regaring successful storage is that fixatives or other methods of preserving may convert the graft into a foreign substance which will incite connective tissue ingrowth and prevent regeneration.

One other means of bridging a graft deserves at least brief comment and this procedure is called nerve crossing which finds its greatest use in facial paralysis.

In 1879 Drobnik first attempt repair by anastomosis of the spinal accessory nerve to the facial with definite improvement of symmetry. Ballance in 1895 tried the same procedure which resulted in regeneration but no dissociation from shoulder movement. Cushing (1903) reported the same results and stated that there may or may not ever be dissociation of movements. Korte (1903) used a hypoglossal-facial anastomosis because, although associated movements of the tongue were inevitable, these movements were not obvious with the tongue in the mouth whereas associated shoulder movements following use of the spinal accessory are very obvious and embarassing to the patient.

Nerve crossing as autologenous grafting is limited because it necessitates loss of function of the part previously supplied by the crossed nerve.

CONCLUSIONS

In view of the facts which have been reviewed in this paper several broad conclusions may be drawn:

1. Chances for successful functional recovery of a severed nerve depends upon re-establishment of anatomical continuity of neurilemma tubes with maintanence of physiological conditions, and the degree of recovery is determined by the degree to which these two factors are established and maintained.

2. Failure to recover function after regeneration of fibers as seen following rotation of stumps and nerve crossing tends to show that there is a central nervous system factor which influences recovery of function and that re-establishment of anatomical continuity of neurilemma tubes involves more detail then mere gross apposition of severed nerve ends.

3. The introduction into the site of injury of sheaths, grafts, sutures, fibrin, foil or other materials may alter continuity or physiological conditions or both; hence, their use requires careful evaluation and weighing of extent and direction of these alterations against possibilities of success without using them.

4. The confusion surrounding evaluation of the

above mentioned materials indicates that experimental studies must be continued to yield and explain the basic factors involved.

While preparing this paper, I encountered a question which went unanswered. With no experimental evidence nor experience to back my belief, I am wondering if perhaps the reason for poor results with heterografts is not based on presence of foreign protein in the graft inciting connective tissue reaction and imposing a block against down growing fibers; and, if this reason is true, could not the same principle be applied to other materials used at the site of injury?

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