U. of M.

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Alfred Washington Adson final oral examination for the degree of Master of Science in Surgery. We recommend that the degree of Master of Science in Surgery be conferred upon the candidate.

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June 1 1918

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REPORT

of

Committee on Thesis.

The Undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Alfred Washington Adson for the degree of Master of Science in Surgery. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science in Surgery.

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June 1, 1918

THESIS

EXPERIMENTAL AND CLINICAL RESULTS OF NERVE ANASTOMOSES

Alfred Washington Adson

Submitted to the Graduate Faculty of the University of Minnesota in partial fulfillment of the requirements for the Degree of Master of Science in Surgery.

I wish to present a combined study of experimental and clinical nerve anastomoses. The experimental work consists of a comparative study of nerve anastomoses in which modern technics have been employed, and the determination of the amount of regeneration has been obtained. The clinical study comprisee the surgical results of nerve anastomoses on patiente operated on in the Mayo Clinic up to January 1, 1917.

Review of the literature

The modern work on the regeneration of nerves may be said to have been begun by von Büngner in 1891, by Howell and Huber in 1892, by Ströbe in 1893 and by Huber in 1895. von Büngner in 1891 called attention to the nucleated protoplasmic bands which have occupied so prominent a place in the histogenesis of regenerated nerve fibers. He emphasized the point that the nuclei of the neurolemma increase in number and that the protoplasm accumulates about them. Howell and Huber in 1892 observed the presence of protoplasmic bands (Bandfäsern) but regarded them as embryonic nerve fibers capable of receiving and transmitting impulses. Ströbe in 1893 was able to demonstrate the outgrowth of axons from the central end but believed that the myelin sheath was formed as a continuation of the old sheath. Huber in 1895, working with Ströbe's technic, was able to show that the axons grew from the central stump and in some cases entered the substance of the protoplasmic bands in the distal segment. Two theories of regeneration were held at this time, the first, presented by Waller in 1852, that the axons grew out from the central end, that complete degeneration takes place from the severance of the nerve proximal to the node of Ranvier, and distally through the entire peripheral nerve; the second, that the axons do not degenerate in the peripheral stump after they have been separated and that all that is necessary for an axon to functionate is the fusion with the central axon and the development of the new myelin sheath about it.

The two theories were discussed by various men up to the time (1912) Ranson presented his work on the degeneration and regeneration of nerve fibers, in which he verifies Waller's investigation and gives a very clear description of the processes of degeneration and regeneration, as well as a very thorough review of the literature. In 1915 and 1916 Lewis and Kirk also present a very complete histologic study of nerve regeneration.

Nerve anastomoses have been accomplished by the following methods: Létiévant suggested making flaps from either the central or the peripheral stump of the divided nerve, or from both the central and peripheral stumps. When it has been impossible to bring about an immediate approximation of the nerve ends, various materials have been used to bridge the gap. Assaky recommended a bridge of catgut between the severed end; Vanlair, decalcified bone tubes; Payr, magnesium tubes; Foresman, celluloid tubes; Lotheissen, gelatin tubes; Foramitti, hardened arteries of the calf; Denk, Döffner, Kredel, and Lewis and Kirk, fascia lata tubulization; Corbett and Beckman, vein tubulization; Sherren, Cargile membranes; Auerbach, galalith; Assaky and Huber, nerve transplants, and Feiss, the fusion method of overlapping the ends and ligating them with silk or chromic catgut.

All of the various technics have been discarded except (1) the flap method, (2) the fusion method, (3) fascial tubulization, (4) vein tubulization, (5) Cargile membranes and (6) nerve transplants.

The nerve flap method, described by Létiévant and Gratz has been followed by many operators in general surgery. The results of such operations have not been reported very accurately, but the usual report given is that the patients have improved, although the exact degree of improvement obtained is not stated.

The fusion method was advocated and tried out experimentally by Feiss, who felt that regeneration depended more on the regenerating scar than on the approximation of the nerve ends.

Fascial tubulization was brought to our attention recently by Lewis and Kirk, who have presented a study on experimental tubulizations as well as reports of clinical tubulizations. However, the fascia lata had been used by former workers such as Denk, Döffner and Kredel.

Vein tubulization was described by Corbett, who employed very much the same technic used by Lewis and Kirk in their fascial tubulization, namely, removing a large portion of vein, dividing it longitudinally and placing it about the severed ends of the nerve as a piece of fascia. Beckman used the resected vein as a closed tube, slipping the cuff of vein over one of the nerve ends prior to anastomosis and then bringing the vein back over the intervening gap, surrounding the cylinder of silk.

Sherren recommended the use of Cargile membranes - the fixed peritoneal membranes of the ox, for the purpose of tubulization.

Nerve transplants were suggested and tried experimentally by Philipeaux and Vulpian. They were used by Assaky in clinical cases and by Huber in a series of experimental cases. Huber reports 26 experiments made on the foreleg nerves of dogs. Ten were observed long enough to admit of regeneration of the peripheral stump, 5 of which presented complete and 4 nearly complete return of function.

In reviewing the literature of the subject it is rather difficult to classify the results of the various operations. Speiser in 1902 collected 208 cases of nerve suture which were combined with 129 cases collected by Schmidt. Of the 337 cases operated on, 224 (66.5 per cent) obtained good results, 53 (15.5 per cent) obtained partial relief, while 60 patients (18 per cent) were not improved by the operation.

Sherren reported 50 per cent for four successful cases out of 8, by the auto- and homo-transplant methods, and 37 per cent of successes out of 22 cases of hetero-transplants (Huber).

Oberndörffer's statistics, dealing with 167 cases of nerve suture, report 96 cases which were operated on the first day after the injury, with good results in 38 per cent, fair results in 35 per cent and failures in 16 per cent of the cases, the results in 11 per cent being unknown. In the remainder of this group in which operations were done from two to seven days after the injury, good results were obtained in 35 per cent and fair results in 52 per cent of the cases, with unknown results in 15 per cent. In the operations done from eight to fourteen days after the injury there were good results in 57 per cent and fair results in 43 per cent. In operations from three to four weeks after the injury there were good results in 56 per cent and fair results in 32 per cent of the cases, with failures in 12 per cent, and in the operations from five to eight weeks after the injury good results were obtained in 44 per cent, in 25 per cent fair results, and in 31 per cent no improvement.

In reviewing the statistics dealing with nerve suture, compiled by fourteen different men, it is found that good results were obtained in 70 per cent of the cases.

Histology

A brief histologic review of peripheral nerves will call to mind that the fibers of medullated nerves arise from the anterior horn cells and join the fibers from the dorsal root which contains both medullated and non-medullated fibers (Ranson), the non-medullated nerve fibers having their origin in small ganglion cells in the dorsal ganglion, presenting axons surrounded by a neurolemma without myelin. The medullated nerve fiber has an axilemma next to the axis cylinder and then the myelin sheath, surrounded by a neurolemma (Schwann's sheath). The myelin is divided up into segments by the nodes of Ranvier. Elongated cells are associated with Schwann's sheath, which are of the utmost importance during the process of regeneration. (Plate 1).

Degeneration and regeneration

Immediately following the division of the nerve, abortive regenerative processes take place, that is, the axis cylinder in both the proximal and distal stumps (but more pronounced in the proximal end) develops a fibrillar disintegration of the axis cylinders with an outgrowth of fibrillae within neurolemma. This process extends back for a distance of about three millimeters and begins within the first 36 to 72 hours following the severance of the nerve. At the same time the nuclei associated with the Schwann's sheath start a process of hyperplasia which begins with enlargement of the nucleus and a granular deposit in the cytoplasm. The Wallerian degeneration begins about the third day and is quite complete on the twelfth day except for resistant axons and myelin granules which may be seen for several weeks. This process consists of a granular disintegration of the axon in the distal end and of the axon in the proximal end up to the first node of Ranvier. The myelin begins to disintegrate and forms droplets of fat within the neurolemma, thus giving a positive black stain with Marchi's method, whereas the normal myelin gives a yellow stain.

The regenerative process is continuous with the degenerative process, first, in that the nuclei of Schwann's sheath multiply very rapidly and fill the empty lumen of the neurolemmal sheath in the distal end as well as the sheaths from the site of severance to the first node of Ranvier; then, if the intervening gap between the severed ends is not too long, or is protected by some form of tube, these cells will send out protoplasmic bands, having a gray, gelatinous appearance, which fill the intervening gap. Simultaneously the axon has sent out numerous neurofibrillae, numbering from five to fifteen, which grow downward through the mass of protoplasmic bands, and, if the gap has been bridged by these bands, they follow the bridge and enter the distal nerve segment. It is not uncommon to find two or three axons following a single protoplasmic band. Many of the axon fibers, however, will fail to enter the distal nerve segment and will produce an oval enlargement at the site of anastomosis, known as a neuroma.

The protoplasmic bands and cells arising from neurolemmal sheath not only assist in keeping the lumen of the distal segment open and bridge the intervening gap between the nerve ends, but they apparently arrange themselves and act as a reticulum, forming the mesh work in which the myelin is deposited, and the nerve completes its process of regeneration.

The following outline is quoted from S. Walter Ranson:

"Early changes in the distal stump
1. Degeneration of the medullated fibers and formation of nucleated protoplasmic bands
2. Degeneration of the non-medullated fibers and the formation of nucleated protoplasmic bands
3. Abortive autogenous regeneration in the distal stump

Early changes in the proximal stump
1. Changes in the non-medullated fibers
   Early abortive regeneration
   Cellulipetal degeneration
   Formation of new axons
2. Changes in the medullated fibers
   Formation of a zone of reaction
   Fibrillar dissociation
   Early branching of the axons in the immediate neighborhood of the lesion
   Formation of lateral branches at some distance above the lesion
   Formation of fiber bundles and skeins

Mechanism of the regeneration of nerve fibers
1. Proliferation of axons in the central stump
2. Penetration of the new axons through the scar
3. Utilization of the protoplasmic bands as pathways for the new axons in the distal stump." (Plates 17,18 and 19).

Experimental study

The experimental study has been carried on more than two and one-half years, during which time 76 dogs have been operated on and 189 operations performed. Twenty-four of the 76 dogs either died too soon to show results or the specimens obtained were destroyed in preparation, thus leaving 52 dogs, or 112 operations in which valuable results were obtained. These operations form the basis of this report.

The dogs operated on were fox terriers and mongrels, small dogs being preferable because of the fact that they are better able to carry the paralyzed extremity than the larger dogs. Previous to operation, the dog fasts for twenty-four hours. The field is shaved and the operation is performed under general anesthesia, given by the intratracheal method. After the operation the dog is kept in a small cage until he recovers from the anesthetic. If the operation has been done on the ulnars the dog may soon be permitted to run about with others, but if done on the sciatics, it is necessary to keep the dog in a small pen to prevent the paralyzed leg from becoming traumatized, which tends to produce very large ulcers on account of trophic disturbances.

The nerves used during the experimental study are: the posterior tibials, the femorals, the sciatics, the external and internal popliteals and the ulnars. It was found that the small nerves such as the femorals and posterior tibials are not as satisfactory as the ulnars and sciatics. Again, the ulnars are preferable to the sciatics inasmuch as an operation on the former does not so greatly incapacitate the dog.

In exposing the nerve, the usual surgical technic is employed; that is, the field is prepared with benzine and iodin, and after the incision is made the edges of the skin are covered with sterile towels. The nerve is then dissected free, a portion of it resected and the ends anastomosed, extreme care being used in applying the sutures so as not to crush the nerve axons, but inserting the sutures into the nerve sheaths. It is of the utmost importance that hemostasis is complete before the wound is closed. All bleeders are tied with fine catgut, No. 0 plain, and the deep fascia is closed with No. 1 chromic catgut, while the skin is closed with interrupted sutures of silk. These are placed close to the skin margins so they will cut through of their own accord. The wound is then painted with iodin and left exposed.

Studies of the regenerative changes have been made at intervals varying from a few weeks to several months following the operation. The method of determining the amount of regeneration is a quantitative one and is based on three technics, (1) anatomical and physiological, (2) electrical, and (3) histological.

The anatomical and physiological results are determined by the amount of atrophy, the use or disuse of the extremity, the presence or absence of trophic ulcers and edema, and the anatomical appearance of the regenerated nerve.

The electrical results are determined by the use of the Harvard Induction Coil, before removing a portion of the anastomosed nerve. The dog is anesthetized and the anastomosed nerve exposed, freed from the surrounding scar tissue, and the portion above the anastomosis stimulated with a low tetanizing current. If a response is elicited, the nerve is severed above the anastomosis and again stimulated. If reaction of the muscles still is present the nerve is crushed with forceps below the anastomosis which results in the loss of the transmission of stimuli through the regenerated portion.

The histological results must be quantitative, and in the cases herein reported were made independent of the anatomical or electrical results, inasmuch as they were studied and classified without reference to the anatomical or electrical results. A number of the specimens were cut in serial sections, including the proximal end, the intervening gap, and the distal end. These were prepared by the Ranson-Cajal pyridine silver method; some of the regenerative processes were studied by Marchi's method. Others were studied by the Cajal-Bielschowsky method. The protoplasmic structure of the myelin sheath was stained by Mallory's phosphotungstic acid hematoxylin stain. The method of choice is a modification of the Ranson-Cajal in which sections of the distal end were studied, both cross and longitudinal sections being made. In determining the amount of regeneration present, the axons in the cross sections were compared with the number of axons present in the normal nerve. It is very difficult to give an absolute estimate but one can readily give a comparative percentage basis. The following methods were used in studying the histological changes during the processes of degeneration and regeneration of peripheral nerves:

Complete serial sections were made of a number of the specimens, including sections of the proximal end, the intervening scar and the distal end. These were carried through the usual Ranson-Cajal technic and Marchi's method, but in view of the good results that have been obtained from the use of frozen sections, the technic was modified to such an extent that the specimens were not embedded in paraffin and then sectioned, but the distal segments of the nerves were prepared for the frozen section method (the method employed at the Mayo Clinic) as follows:

Fix the nerve section in 10 per cent formol for 3 days
Wash one minute, cut frozen sections and place in distilled water
Place in 80 per cent alcohol for five minutes
Place in 95 per cent alcohol for five minutes
Place in 99 per cent alcohol for one minute
Place in carbo-xylol for five minutes
Place in xylol for two minutes
Mount in Canadian Balsam.

Mallory's phosphotungstic acid hematoxylin method, employed by Lewis and Kirk, is the one used in studying the protoplasmic bands and reticular mesh work of the newly formed myelin sheaths of the regenerated nerves.

The osmic acid method is also of value in studying the presence of medullated fibers. Small specimens are placed in 2 per cent osmic and changed daily for four days, after which the specimens are washed thoroughly and carried through the usual frozen section method. The myelin and fat take a very black stain, but the rest of the tissue remains clear unless counter-stained by saffron.

Marchi's method is valuable in studying the degenerative processes as the normal myelin takes a yellow stain, while the degenerated myelin takes a black stain, which is the osmic stain of the fat particles in the degenerating sheaths. Weigert's method gives only the negative results, while Marchi's method gives both positive and negative results. The technic is as follows:

Fix in Muller's fluid for one week
Place in 2 parts Muller's fluid and 1 part 1 per cent osmic for 3 days
Wash thoroughly and follow with the usual frozen section method.

The Ranson-Cajal method is excellent for bringing out the non-medullated regenerating nerve fibers, which take on a very black appearance, while the medullated axons present a darkish brown appearance. The technic is as follows:

Fix in ammoniacal alcohol (50 c.c. of alcohol with 4 drops of ammonia) for two days - divide as follows:
Place in 60 per centalcohol with ammonia for twelve hours
Change to 75 per cent alcohol with ammonia for twelve hours
Change to 85 per cent alcohol with ammonia for twelve hours
Change to 90 per cent alcohol with ammonia for twelve hours
Rinse in several changes of distilled water until specimen sinks
Place in pyridine for twenty-four hours
Wash in several changes of distilled water for twenty-four hours
Place in 5 per cent silver nitrate solution, in 37½° oven for three days; changing silver daily
Wash quickly in three changes of distilled water

Place in the dark for twenty-four hours in a developing solution made up of
Pyrogallic acid - 5 gms.
Formalin(Formaldehyde)40 per cent - 5 c.c.
Distilled water - 40 c.c.
Wash and cut frozen sections and place in distilled water
Dehydrate and mount in usual manner.

The gradual dehydration and fixation process prevents shrinking of the axons.

The specimen may also be taken from a 10 per cent formal in and passed through the pyridin--silver method by simply washing the specimen before placing it in the pyridin.. Otherwise the technic is the same. This gives as good histological pictures as the ordinary Ranson-Cajal method.

The Levaditi and Bielschowsky methods are valuable but in my experience have not been as successful as the Ranson-Cajal. In comparing the results obtained from the use of the various technics, it has been my experience that the fresh tissue - cross and longitudinal sections - carried through the Ranson-Cajal frozen section method gives by far the best histological changes, as the axons are not shrunken or distorted. Following are the comparative results of operations performed by the various technics:

PLASTIC OPERATIONS: THE SPLITTING AND TURNING OF FLAPS

Operations (without gaps 3; with gap 1) 4
Average regeneration
Anatomical . . . . 76.6 per cent
Histological . . . . 83.3 per cent

FUSION METHOD

Operations (6 cases nerve overlapped and ligated with catgut, 15 cases nerve overlapped and ligated with silk) 21

Six cases ligated with catgut, average regeneration
Anatomical . . . . 60.8 per cent
Electrical . . . . 50 per cent
Histological . . . . 60 per cent

Fifteen cases ligated with silk, average regeneration
Anatomical . . . . .73.4 per cent
Electrical . . . . 71.8 per cent
Histological . . . . 61.8 per cent

The significant facts to be noted in these cases are that the results are better in the small nerves, are failures in the large nerves when ligated with catgut, and only fair when the medium sized nerves are ligated with silk. (Plate 2).

NERVES CUT AND PERMITTED TO FALL BACK INTO SHEATH - NO ANASTOMOSIS

Operations	13
Average regeneration	
Anatomical	58 per cent
Electrical	47.8 per cent
Histological	63.2 per cent

The important fact to be noted in this group is that the nerves are permitted to fall back into their own sheaths without trauma of the nerve ends except for their severance with a sharp instrument. A few of these were permitted to fall back into the sheath under septic conditions, but at no time were the wounds traumatized or badly infected. Comparing these experimental results with the clinical it is found that while a certain amount of regeneration is obtained in the experimental cases, none is obtained in the clinical cases owing to the fact that the nerve ends have been macerated and displaced from their own sheaths from the trauma that produced the wound. (Plate 3).

ANASTOMOSES WITH SILK, WITH FASCIAL COVERING

Operations	10
Average regeneration	
Anatomical	82.5 per cent
Electrical	100 per cent
Histological	79 per cent (Plate 4).

FASCIAL TUBULIZATION, - LEWIS AND KIRK METHOD

Operations	6
Average regeneration	
Anatomical	Questionable
Electrical	Negative
Histological	91.6 per cent (Plate 5).

ANASTOMOSES WITH SILK AND ANIMAL MEMBRANE

Operations	18
Average regeneration	
Anatomical	69.2 per cent
Electrical	71.4 per cent
Histological	77.8 per cent

The important fact to be noted in this group of cases is that the animal membrane, which is very similar to Cargile membrane, is sufficient to act as a protection in short gaps, but is of no value where the gap is more than 12 mm. because of the fact that the membrane disintegrates before the axons reach the distal end. (Plates 6, 7 and 8)

ANASTOMOSES WITH SILK, COVERED WITH VEIN

Operations 6
Average regeneration
Anatomical . . . . 83.3 per cent
Electrical . . . . .Negative
Histological . . . . 82 per cent

The vein in this group was applied in a manner similar to that in the Beckman technic, the cuff of vein being slipped over one end, without dividing the vein, before the anastomosis was made.

VEIN TUBULIZATION - CORBETT METHOD (Plate 9).

Operations 6
Average regeneration
Anatomical . . . . 25 per cent
Electrical . . . . .11.2 per cent
Histological . . . . 76 per cent

This method is the one employed by Corbett and is very similar to the method of Lewis and Kirk, except that vein is used instead of fascia. The cases in this series were of short duration, the longest 40 days, the shortest 27 days, which accounts for the low anatomical and electrical regeneration. However, the histological results give a very accurate picture of the regeneration in the distal end close to the anastomosis. (Plate 10).

ANASTOMOSES WITH CHROMIC CATGUT

Operations (1 with covering, 1 without covering). 2

Both were failures.

ANASTOMOSES WITH SILK, NO COVERING

Operations (2 with gaps, 1 of 7 and 1 of 15 mm.,
5 without gaps) 7
Average regeneration
Anatomical .85.7 per cent
Electrical .90 per cent
Histological . . . . .82.5 per cent

ANASTOMOSES WITH SILK, COVERED WITH BONE TUBES

Operations (complete failures). 3

The technic employed in these cases was similar to that described by Vanlair; the failures were due to the fact that the bone tubes acted as foreign bodies, resulting in the tearing out of the sutures between the nerve ends and the point where the tube was sutured to the perineurium.

ANASTOMOSES WITH SILK, COVERED WITH FIBER TUBES

Operations (failure) 1

This anastomosis was made in a manner similar to the bone tube method and the failure was very likely due to the technic as in the case of the bone tubes.

AUTOGENOUS TRANSPLANTS

Operations	3
Average regeneration	
Anatomical	85 per cent
Electrical	85 per cent
Histological	43.3 per cent (Plate 11

NERVES CRUSHED WITH FORCEPS

Operations	5
Average regeneration	
Anatomical	70 per cent
Electrical	50 per cent
Histological	82.5 per cent

The longest period of anastomosis in this group was 197 days, the shortest 47 days.

NERVES LIGATED WITH CATGUT (Plates 12 and 13).

Operations	4
Average regeneration	
Anatomical	Questionable
Electrical	.22.5 per cent
Histological	.70 per cent (Plate 14).

It should be noted in this group that the duration of the anastomoses was comparatively short, the longest being 71 days and the others from 23 to 45 days.

NERVES LIGATED WITH SILK

Operations 3
Average regeneration
Anatomical . . . . Questionable
Electrical . . . . Failure
Histological . . . . 95 per cent (Plates 15 and 16)

SUMMARY OF EXPERIMENTAL RESULTS

Seventy-six dogs were operated on and 189 operations were performed.

Twenty-four dogs (77 operations) either died too soon to be of value in the study of regeneration or the specimens taken from them were destroyed in their preparation.

Fifty-two dogs (112 operations) were sacrificed or died long enough after the operation to be of value in the study of regeneration.

The present study therefore is based on the results of 112 operations for nerve anastomoses, most of which were done as primary anastomoses under sterile procedures, immediately following severance of the nerve. A few were done as a secondary repair of nerves divided previously under septic conditions. The average duration of the anastomoses was 150.5 days or five months. Fifty of the dogs lived more than six months, thirteen lived one year or more.

The anastomoses were done on 11 tibials, 21 femorals,31 sciatics and 49 ulnars. Twenty-nine of the operations were end-to-end anastomoses with absolute approximation, 29 in the series either overlapped or were not severed, in 62 there were gaps, with an average length of 10.6 mm., which does not include one case that regenerated a distance of 4 cm.. The anastomosis in this particular case was a resection of one half of the sciatic nerve; the ends were held on tension by silk sutures, and the gap and the remaining portion of the unsevered nerve were surrounded by a tube of animal membrane.

Regeneration took place in 105 (93.4 per cent) of the 112 cases, giving an absolute failure in only 6.6 per cent of the cases. The high percentage of regeneration is accounted for by the fact that a case is classified as a regeneration irrespective of the amount, and that most of these anastomoses were primary on freshly severed nerves. The degree of regeneration is estimated quantitatively as accurately as possible. This group of cases presented an average anatomical regeneration of 64.5 per cent, an average electrical regeneration of 62.9 per cent, and an average histological regeneration of 74.8 per cent.

The anatomical regeneration is based on the absence or presence of atrophy, the absence or presence of edema and trophic ulcers, the use or disuse of the extremity, and the appearance of the anastomosis and the distal end at the time of autopsy. The electrical regeneration is determined by the response of the stimuli, previously described. This is rather difficult to determine accurately as it is apparent that a few completely regenerated nerves are capable of producing as strong a muscular contraction as a nerve that has twice as many regenerated nerve fibers. It is also true that the electrical response will be negative when the regeneration through the scar and into the distal end has taken place but has not become complete through the entire distal nerve segment. This discrepancy is very obvious in the dogs sacrificed from three to eight weeks and longer after the operation, depending on the size and length of the nerves. The determination of the histological results is based on the comparative number of regenerated medullated and non-medullated neurones present. This is best determined by examining the cross sections of the specimens in conjunction with the longitudinal sections. The new axons and the increase of connective tissue, and frequently the old neurolemmal sheaths filled with nucleated cells may readily be seen.

After regeneration has taken place through the interneural scar many axons following the protoplasmic bands are seen, a large number of which are non-medullated axons, but many neurofibrillae are seen in groups in the early regenerative stage which either line themselves into axis cylinders, or disappear. Others hypertrophy. But during this early stage there is no myelin, and the protoplasm stains brown, while all of the neurofibrillae and axis cylinders stain black. However, it is obvious, on examining a similar section in the later stages of regeneration, that the number of medullated and non-medullated axons is smaller than the number of neurofibrillae and axis cylinders seen in the earlier stages of regeneration. The distribution of regenerated nerve axons through the interneural scar and distal segments depends directly on the amount of scar tissue in the neuroma. If there is very little of the fibroblastic tissue, the axons will grow down in large columns and give a good regeneration while if there is a large amount of scar tissue the axens will be scattered in small groups, giving a poor regeneration, as there are more possibilities of diverting the axons from their normal course and a possibility of constriction of the axons by the organizing fibrous tissue.

CLINICAL STUDY: - OPERATIVE INDICATIONS

Very complete and accurate history taking, combined with a very thorough neurological examination, are extremely essential in all patients that are considered for operative treatment.

1. The nerve should be sutured whenever possible immediately following the injury, even in the presence of infection, as frequently the suturing will prevent retraction of the severed ends.

2. A reasonable length of time should be given following the injury (six months) when there is some doubt as to the extent of the lesion, as possibly the injured nerve may regenerate.

3. Late cases coming with definite evidence of complete severance of the nerve should be explored and operated on as soon as the wound is free from latent infection.

4. Nerve injuries may be explored and repaired with reasonable success up to a period of five years, but after that the results of operation are very questionable. However, in some excellent cases there has been return of function up to ten years and more.

5. Good results may be obtained when portions of the nerve have been destroyed, leaving a gap between the severed ends up to one inch, but the results

are very poor if the gap is longer than one inch. The intervening gap, however, frequently may be shortened by slight stretching of the nerve and flexion of the extremities.

6. When there is a distance of an inch or more between the severed ends of the nerve, it occasionally is advisable to consider resection of bone to permit the approximation of the nerve ends or muscle transplantation.

OPERATIVE FINDINGS

There are three clinical conditions found at operation:

1. Cases in which the nerve has been completely severed, with retraction of the nerve ends, presenting neuromata on each end. The neuroma on the proximal end is usually about twice the normal size of the nerve, while the neuroma on the distal end is very small, only about one and one-fifth times the size of the normal nerve. The portion of the nerve above the proximal neuroma is enlarged to about one and one-sixth times the normal size of the nerve; it is edematous and injected, as well as having a rather soft, mushy feel.

2. Cases in which there is a diffuse thickening of the nerve, due to trauma, usually over some bony prominence (for example, a very common lesion is that found in the ulnar nerve, where it is situated over the inner condyle of the humerus and anterior tibial, which passes around the head of the fibula). The proximal end of the nerve is normal in appearance and size, while the distal end is enlarged, edematous and injected, the enlargement being about one and one-sixth times the size of a normal nerve. The neuroma itself presents a mass of scar tissue and frequently contains axons.

3. Cases in which the condition is due to constriction of the nerve by an exuberant callus, the most common example being the musculo-spiral nerve, which is strangulated by the callus which forms following fracture of the humerus. The histories of these patients are very significant in that the paralysis is progressive and comes on several weeks after the injury, differing from the first condition described, where the paralysis is complete, and differing from the second condition

whaxaxthaxparalyaiaxiaxaampiataxxandxdiffaringxframxthaxaaaandxaanditian where the paralysis comes on from a few hours to several days following the injury. The nerve proximal to the constriction is normal in appearance and size, while the portion distal to the constriction is frequently smaller in size than the normal nerve and not edematous or injected unless the constriction is complete. The appearance is the same as is seen in the second group in which trauma has bruised the nerve, crushing the myelin and the axis cylinders.

Paralysis of the seventh nerve may be due to severance or to inflammatory processes of the temporal bone, or injuries of the bone during a mastoid operation.

OPERATIVE TREATMENT

When the nerve has been completely severed, the severed ends will be retracted but generally in the line of its original position. It is usually adherent to the mass of scar tissue so it is quite important to expose normal nerve above and below the scar, after which the ends should be freed with very gentle manipulation. After the neuromata have been exposed it is essential that all of the neurematous scar tissue be removed in the proximal end so that the bundles of nerves stand out as little brushes. The neuroma on the distal end must be excised to such a degree that the definite nerve sheaths can be made out. The bleeding is usually controlled by allowing the cut ends of the nerve to come in contact with dry sponges for five or ten minutes. If this is not sufficient, usually the vessel may be tied with fine catgut.

In anastomoms of the nerve the sutures are applied to the sheath (epineurium) surrounding the nerve. They are inserted obliquely into the sheath, thus bridging the gap with a cylinder of silk, of five or six strands to the nerve. If the ends can be brought in close apposition, no fascial covering is necessary. If there is much tension, fine silk is preferable to chromic catgut. When it becomes necessary to leave a gap between the nerve ends it is important that this gap should be covered by some membrane or fascia. The fascia lata is the one of choice and is described very thoroughly by Lewis. However, an absolute apposition is preferable to a gap, as the prognosis is usually much better, so one should remember that the nerve will stand gentle stretching and that the extremities may be flexed to relieve tension. (Plates 21 and 22).

In cases in which the condition as described in the second group, is found the surgical procedures are as follows: After exposing the nerve with the neuroma, the operative treatment depends on the amount of paralysis present. If the paralysis is less than 50 per cent, the epineurium and perineurium are divided so as to liberate the normal neve fibers, but if the paralysis is more than 50 per cent the neuroma is resected, exposing normal nerve fibers above and the definite nerve sheaths below, and anastomosing the ends in the same manner as when the nerve has been completely severed. (Plate 23). This distinction is made on the ground that if the patient has 50 per cent of function and further paralysis can be prevented, it is much better for the patient to go with a slight handicap than to have the nerve resected and anastomosed, taking a chance of only a partial return of function.

In the third group of cases in which the condition is due to constriction of the nerve by callus, the surgical treatment again depends on the amount of paralysis present. If the paralysis is less than 50 per cent, the nerve is freed from the surrounding scar tissue and protected by a cuff of fascia. If the paralysis is more than 50 per cent, the constricted area is resected and anastomosed as herein described. (Plate 24).

The surgical treatment of facial paralysis depends in some degree on the cause of the lesion, and it is better to wait a reasonable length of time (nine months) after the injury before advising operative treatment, unless it can be determined that the nerve is completely severed, then operation should be undertaken as soon as the latent infection has cleared up. If at the end of nine months there is no sign of regeneration, one of two courses may be followed, anastomosing the distal end of the seventh nerve to the hypoglossal, or to the spinal accessory, preferably the latter.

INCISION

An incision is made along the anterior margin of the sterno-mastoid, extending slightly above the mastoid prominence of the temporal bone. The sterno-mastoid is turned outward and the internal jugular vein is retracted inward. The dissection is carried into the cervical fascia until the posterior belly of the digastric muscle is exposed. Underneath this and running at right angles to it, the spinal accessory is exposed from the lower margin of the posterior belly of the digastric to its entrance into the sternomastoid muscle. The seventh nerve is exposed by carrying the dissection upward toward the stylomastoid foramen, exposing the tendinous portion of the stylohyoid muscle, which has its origin one-half inch mesially to the exit of the seventh nerve, which is situated three-fourths of an inch upward and inward from the prominence of the mastoid portion of the temporal bone.

ANASTOMOSIS

The seventh nerve is divided at its exit from the stylomastoid foramen and its distal end is brought down and anastomosed to the proximal portion of the spinal accessory, which has been divided at its entrance into the sternomastoid muscle and turned upward over the posterior belly of the digastric muscle. The anastomosis is made with interrupted sutures of silk, after the nerves have been brought together in accurate approximation. It is not necessary to cover the anastomosis but inasmuch as the external jugular vein is encountered it is convenient to remove a section of this vein which can be applied as a cuff over the anastomosis, making the apposition still more complete. It is true that a little atrophy will be observed in the trapezius on account of the destruction of the spinal accessory, but this is of very little consequence as compared with the facial paralysis. (Plate 25).

CLINICAL STUDY IN 41 PATIENTS OPERATED ON FOR SOME FORM OF NERVE ANASTOMOSIS

These 41 patients were studied neurologically prior to operation and a number of them returned and were examined after regeneration was either partial or complete. In conjunction with the postoperative study, follow-up letters have been sent to the patients; thus in reporting as to the amount of regeneration obtained it is necessary to give the opinion of other physicians and that of the patients. All of the patients have been operated on a year or more.

Nine facial anastomoses were made (5 females and 4 males), the average age of the patients being 24 years. Eight (89 per cent) of the 9 patients have been examined at intervals following operation or have reported by letter. The average duration of the injury before the anastomosis was made was 26 months. Three patients were operated on within the first year following the injury and all presented an improvement of from 60 to 85 per cent in return of function. The patients operated on at intervals up to 5 years presented an improvement up to 50 per cent of function. One patient, with a 15 year history, failed to reply to our follow-up letter. The injury of the nerve in 2 cases was due to a mastoid operation and in 7 cases to a lacerated wound in the region of the seventh nerve. In 8 cases the anastomosis was to the spinal accessory, in 1 case to the hypoglossal. In 8 cases an end-to-end anastomosis was made, 3 of which were covered with fascia, 4 with vein and 1 was left uncovered. In 1 case the anastomosis was by the Feiss method, in which the ends were overlapped and ligated with silk. Following the anastomoses, the average time before improvement was noticed was 7.9 months; the average time of maximum improvement was 18.5 months. The average amount of motor return was 71 per cent of the normal function, arrived at by quantitative examination as to the power and control of the facial muscles.

In summing up the results of facial anastomoses, it is found that 89 per cent of the patients were heard from, all of whom had improved, that the average amount of improvement for the patients reported was 71 per cent, and that in this group there were no failures or indeterminate results, no infections and no deaths.

Seven ulnar anastomoses (1 a female and 6 males) were made. The average age of these patients was 20.4 years. Five (71 per cent)of these patients have been heard from or have been studied following operation. The average duration of the injury before the anastomosis was made was 6 months, the shortest time being 6 weeks and the longest 12 months. Two of the injuries were associated with fractures of the elbow and two with lacerated wounds of the fore-arm. Six of the anastomoses were sutured with silk and one with chromic catgut. Three were covered with fascia. In 5 cases the apposition was direct, without a gap; in 2 there was a gap of one inch between ends. Those presenting a gap were covered with a tube of fascia lata. The average time before improvement was noticed was 10 months following operation, while the average time of maximum improvement was 16.2 months. The amount of maximum improvement in the reported cases was 63 per cent of the sensory, motor and trophic functions. Thus it will be noted that there was improvement in all the cases heard from, that is, 71 per cent of the patients operated on for ulnar lesions, with an average amount of improvement of 63 per cent. There were no failures or indeterminate results, no infections and no deaths.

One radial anastomosis was made. The patient a male, 24 years of age, was operated on 2 months after the injury. The anastomosis was done with silk. Unfortunately the patient has not reported his condition since operation so we are unable to give the results.

Seven median nerves were repaired. All the patients were males, and their average age was 23 years. Six (85.7 per cent) of these patients have been heard from or have been studied following operation. The average duration of injury before operation was 18 months, the shortest time being 6 weeks and the longest 4 years. Five patients were operated on within the first year, 2 gave a four-year history. All the injuries were due to lacerated wounds. In 3 cases the anastomoses were made with silk, 3 with chromic catgut and 1 by means of a plastic operation. Five were covered with fascia and 2 were left uncovered. Direct apposition was obtained in 5 cases; the remaining 2 presented a gap of 1 inch between the severed nerve ends. The average time before improvement was noticed was 10.9

months, the average time of maximum improvement was 21 months, with 72 per cent return of the sensory, motor and trophic functions. To sum up, there was improvement in 71 per cent of the patients heard from, 1 (14 per cent) failure, no indeterminate results, no infections and no deaths.

Ten musculo-spiral anastomoses were performed, all on males, whose average age was 36 years. Nine (90 per cent) of these patients were heard from after operation. The average duration of injury was 28 months, the shortest time being 2½ months, the longest 12 years. Nine of these injuries were associated with fractures of the humerus and one was due to a lacerated wound. Seven were end-to-end anastomoses, with silk and chromic catgut sutures. Two were plastic operations in which a segment of the proximal end was turned down. In one case the nerve was freed from adhesions. In seven cases the anastomoses were covered with fascial tubes. Four of these patients presented a gap of from one-half to one and one-half inches. The average time before improvement was noticed was 12 months, the average time of maximum improvement was 27 months. The amount of improvement in the patients benefited was 72 per cent return of the sensory, motor and trophic functions. Twenty per cent only of these patients received improvement, in 30 per cent the results were indeterminate, and in 50 per cent they were failures. Ninety per cent of the patients were heard from. One patient (10 per cent) became infected. There were no deaths.

Four external popliteal anastomoses were made, all on males, whose average age was 30 years, and all of whom have been heard from following operation. The average duration of injury was 12 months, the shortest time being 11 months, and the longest 16 months. Three of the injuries were associated with lacerated wounds and one with a dislocation of the fibula. Three of the operations were end-to-end anastomoses with silk and were covered with fascia, while the fourth was a plastic operation. The average time before improvement was noticed was 11 months; the average time of maximum improvement was rather indefinite - somewhat more than 24 months. The average improvement obtained was 43 per cent return of the sensory, 30 per cent of the motor and 80 per cent of trophic function. Thus it will be found in this group that 50 per cent of the patients operated on were markedly improved, with an average of 43 per cent return of the sensory, 30 per cent of the motor and 80 per cent of the trophic function. In one case (25 per cent) the result was a failure, and in one case (25 per cent) the result was indefinite. The failure of union in the case of the one patient was due to an infection developing in the wound, giving 25 per cent of infections in these cases, with no deaths.

Two sciatic nerves were repaired. Both patients were males; their average age was 22 years. One had been injured eight years before coming to the Clinic; in the other the time of injury was not ascertained. The injury in one instance was due to a revolver bullet, in the other to a lacerated wound. Both operations were end-to-end anastomoses, one with silk and one with chromic cat-gut; both were covered with fascia. In the one case there was a gap of three-fourths of an inch between the nerve ends. The average time before improvement was noticed was 6 monthw; the average time of maximum improvement was 18 months. One of the two patients (50 per cent) was heard from following operation; the improvement reported was 40 per cent return of the sensory, motor and trophic function. There were no failures or questionable results, except in the case of the patient not heard from following operation, no infections and no deaths.

One right recurrent laryngeal was anastomosed, one year after the injury, the result of a thyroidectomy done elsewhere. The patient was a male, 39 years of age. The operation was an end-to-end anastomosis; the suture material used was not recorded. The time before improvement was noticed was 12 months after the operation, with the maximum improvement at the end of 36 months. The amount of improvement reported was 90 per cent return ofthe motor function. This patient reported an improvement of 90 per cent. There were no questionable results, no failures, no infections and no deaths.

GENERAL SUMMARY OF CLINICAL STUDY

Forty-one patients were operated on; 35 were males and 6 were females. The average duration of injury was 15 months. Seventy-three per cent of the patients have been studied or have been heard from since the operation. Seven of the 41 injuries were associated with fractures, 1 with a dislocated bone, and 33 were directly associated with lacerated wounds. Eighty and five-tenths per cent of the operations performed were end-to-end anastomoses, while the balance (19.5 per cent) were plastic operations of some sort. Sixty-five per cent of the 41 anastomoses were sutured with silk, 29 per cent with chromic alone or with silk and chromic. In 49 per cent, fascia was used in the form of a tube to protect the anastomosis, in 10 per cent, vein was used and in 10 per cent there was no covering. Seventy-three per cent of the anastomoses were in direct apposition, 27 per cent presented gaps varying from one-half to one and one-half inches in length, the average length being one inch. The average time before improvement was noticed was 9.9 months and the average time of maximum improvement was 21.5 months. The average amount of improvement obtained was 58 per cent return of the sensory, 62 per cent return of the motor and 67 per cent return of the trophic function. Seventy-three and one-tenth per cent of all the patients operated on showed improvement, 17 per cent of the operations were total failures, while 9.7 per cent gave indefinite results. Four and eight-tenths per cent of all the wounds became infected. There were no operative deaths.

COMPARATIVE SUMMARY OF VARIOUS EXPERIMENTAL OPERATIONS:

Plastic nerve flap operations.-

These are unsatisfactory for the reason that the nerve flap disintegrates as soon as it is cut loose from the proximal end and then it only acts as a bridging band, which fascia will do as well; then, too, when using fascia or some other material it is not necessary to sacrifice any of the normal nerve for a flap. The percentage of regeneration given experimentally is much higher than ordinarily obtained clinically, and the group studied and reported in this paper is too small for a basis of definite percentage values.

Feiss' Fusion method.- This method is unsatisfactory for large nerves, as the large amount of scar tissue which forms hinders regeneration. The ligation with silk gives slightly better results than with catgut, as the silk cuts through the nerve fibers and liberates the axons into the gelatinous scar, resulting in a partial regeneration. When catgut is used, it is absorbed and the overlapped ends separate. However, even when this occurs, a few fibers reach the distal segment. Clinically we were compelled to use this method in one case in the anastomosis of the spinal accessory to the distal fibers of the seventh nerve. The seventh nerve had been destroyed in a large lacerated wound of the paretid region, and in exploring, only a few fibers of the nerve were found. These were overlapped with the proximal end of the spinal accessory. Eight months later the patient reported that he could grin on both sides of his face, but still had difficulty in closing the eye-lid on the affected side.

Sectioned nerves that are permitted to fall back into their sheath.- The series of sectioned nerves in the experimental study were cut with a sharp knife and permitted to fall back into an uninjured sheath which has resulted in the comparatively high percentage of regeneration. In clinical cases the surrounding tissues are usually macerated and the alignment of the nerve disturbed. These results, therefore, emphasize the fact that regeneration does not depend so much on the type of the operation as on two principles, namely, that the nerve ends must be kept in alignment, and that the intervening gap must not be too long; if it is, some form of tubulization is necessary.

Anastomosis with silk and no covering.- The operation is an end-to-end anastomosis with an absolute approximation. The sutures in thesheath may be either of silk or chromic catgut. If there is tension, the silk should be used. Both produce about the same amount of tissue-reaction and if the histological results in these cases are compared with the histological results in the tubulization cases, the following will be noted:

		Per cent
Anastomosis with silk, no covering	Histological regeneration	82.5
Anastomosis with silk, fascial covering . . .	Histological regeneration	79
Fascial tubulization, Lewis and Kirk method .	Histological regeneration	91.6
Anastomosis with silk, vein covering(Beckman)	Histological regeneration	82
Vein tubulization, Corbett method	Histological regeneration	76

It is obvious that there is very little difference in the amount of regeneration obtained when all types are used for small gaps.

The tubulization methods.- (1) Anastomosis with silk, covered with fascia, (2) vein (Beckman), (3) Lewis and Kirk fascial tubulization method, (4) vein tubulization (Corbett). One of these methods must be employed when it is impossible to bring the nerve ends together, in order to prevent immigration of fibroblasts which produce an obstructing scar. The anastomosis with silk, with the fascial covering, is perhaps the one of choice, as the tubulization results are about the same for short gaps and this gives better results where the gaps are longer, as the silk anastomosing sutures which are kept on tension as supporting columns prevent the collapse of the fascial tube, which will take place in the straight fascial or vein tubulization.

If the gap is small, 1 cm. or less, the Lewis and Kirk tubulization has a slight advantage in that there is no foreign material within the tube. The vein method of Corbett closely resembles the Lewis and Kirk method, except clinically there may be some difficulty in getting a vein large enough without removing one of the external jugulars. The Beckman vein tubulization method, in which the vein is not slit open but is used as a cuff over the silk anastomosis, is a good method when a large vein is encountered in exposing the injured nerve, for example, the external jugular in anastomosing the spinal accessory to the seventh nerve. It is very doubtful if the endothelium of the veins proliferates to such a degree as to hinder regeneration. It was very difficult to follow the histology in the vein surrounding the anastomosis in the specimens studied.

Bone and fiber tubulizations were failures. No covering is necessary where an end-to-end anastomosis with absolute approximation can be made, but in the cases studied in which there were long gaps, the tubes acted as levers and tore out the stitches.

Autogenous transplants act as a bridge but give poorer results than ordinary fascial bands, as the transplants disintegrate and are likely to constrict the regenerating axons, and if the transplants are long a certain amount of constriction will have taken place before the regenerating axons reach the distal end of the transplants.

CRUSHING AND LIGATING NORMAL NERVES

Five nerves (1 femoral, 1 left ulnar, 3 left sciatics) crushed with forceps.
Duration of anastomosis 80 days, presenting an average regeneration of

Anatomical	.70 per cent
Electrical	.50 per cent
Histological	.82.5 per cent

Four nerves (1 left femoral, 2 left sciatics, 1 left ulnar) ligated with catgut
Duration of anastomosis, 46 days, presenting an average regeneration of

Anatomical	6.2 per cent
Electrical	.22.5 per cent
Histological	.70 per cent

Three nerves (1 left sciatic) ligated with silk
Duration of anastomosis 37.6 days, presenting an average regeneration of

Anatomical	Questionable
Electrical	- -
Histological	95 per cent

The following groups were reported by Judd, New and Mann in 1918.

24 recurrent laryngeals, pinched , function restored in 30 to 60 days
9 recurrent laryngeals, ligated with chromic catgut, function lost, (longest duration of anastomosis 371 days)
6 recurrent laryngeals, ligated with plain catgut, function lost, (longest duration of anastomosis 320 days)
4 recurrent laryngeals, ligated with silk, function lost, (longest duration of anastomosis 372 days)

It is obvious that simple crushing of a nerve results in temporary paralysis with a fairly good return of function. The ligation of small nerves such as the recurrent laryngeals with catgut or silk, results in permanent loss of function, while in the larger nerves a partial regeneration takes place.

COMPARATIVE RESULTS

Experimental cases 112: 19.2 per cent plastics, 80.8 per cent end-to-end anastomoses. Fifty-five per cent with gap, 25.8 per cent without gap.

Patients operated on 41: 19.5 per cent plastics, 80.5 per cent end-to-end anastomoses. Twenty-seven per cent with gap, 73 per cent without gap.

REGENERATIVE RESULTS

Experimental cases: 93.4 per cent obtained improvement, 6.6 per cent were failures.

Patients operated on: 73.1 per cent obtained improvement, 9.7 per cent of questionable results, 17 per cent were failures.

DEGREE OF IMPROVEMENT

Experimental cases (whole group): 64.5 per cent anatomical regeneration; 62.9 per cent electrical regeneration; 74.8 per cent histological regeneration.

Experimental cases (tubulization cases): 82.5 per cent anatomical regeneration; 100 per cent electrical regeneration; 79 per cent histological regeneration.

Patients operated on: 62 per cent return of motor function; 58 per cent return of sensory function; 67 per cent return of trophic function.

It is evident that the sooner the anastomosis can be made after the severance of the nerve, the higher will be the percentage of improvement obtained, as all the operations on patients were performed some time after the injury had occurred, while the experimental cases were primary repairs. The failures are higher in the former on account of the longer gaps that had to be bridged. The degree of improvement is from 5 to 20 per cent higher in the experimental cases because the experimental anastomoses were primary repairs, and the intervening gaps were shorter.

CONCLUSIONS

1. The regeneration of the axis cylinders takes place from the proximal axon, and the neurofibrillae will jump a moderate (1-2 cm.) interneural gap

and frequently enter the distal segment.

2. The regenerating axons follow the protoplasmic bands across the interneural gap and grow into or along/aide of the neurolemmal sheaths in the distal segments.

3. Regeneration begins in 36 hours after injury, and is more rapid in dogs than in man, the average time before maximum improvement is obtained being 5 months in dogs and from 18 to 24 months in man.

4. The sooner the anastomosis can be made after the injury the higher the percentage of patients benefited and the greater the degree of improvement.

5. Nerve flap plastics are unsatisfactory and clinically give a low percentage of regeneration.

6. Feiss' fusion method is advisable for small nerves, those that are too small to suture. The ligation should be with silk.

7. No covering is necessary when an absolute approximation has been made.

8. Tubulization should be employed whenever a gap has to be left between the anastomosed ends.

9. Lewis and Kirk's, Corbett's, and Beckman's methods, or the anastomosis with silk covered with fascia may be used for short gaps with equally good results, but the anastomosis with silk covered with fascia is the one of choice in gaps of 2 cm. or more.

10. The operative procedures should be performed under the strictest asepsis and hemostasis possible.

11. In all cases in which the gaps between the severed ends are more than 4 cm. in length, the possibilities of regeneration are very poor and the aid of the orthopedist should be sought, since he can do tendon transference and arthrodesis of joints, which often serve to make fairly useful extremities.

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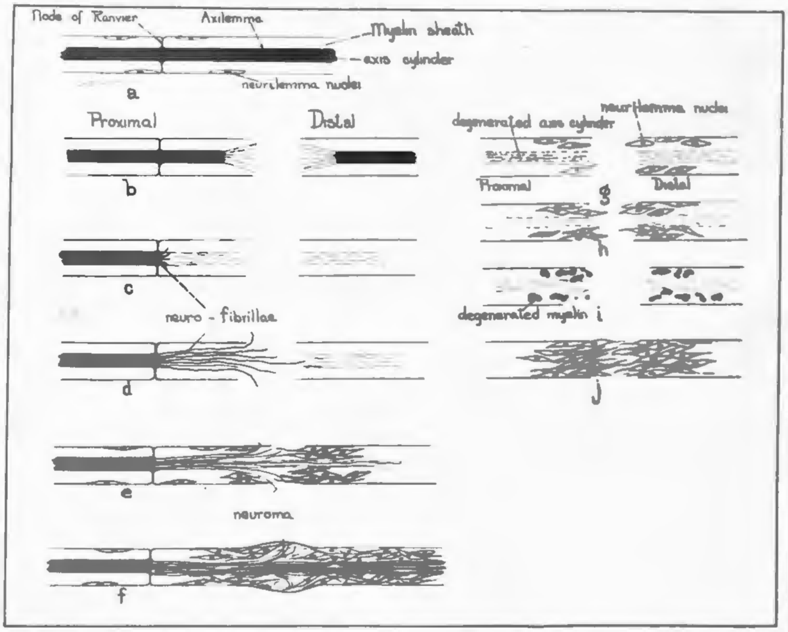
PLATE I.



a. Diagrammatic sketch of a normal medullated nerve illustrating the axis cylinder, axilemma, myelin sheath, neurilemma (Schwann sheath), and its nuclei and the node of Ranvier.

b. Abortive regeneration of the axis cylinder brought out by the Pyridin silver stain (Cajal) on the third day following severance of nerve.

c. Wallerian degeneration of axis cylinders which begins on the third day and is quite complete on the eighth day following severance of the nerve brought out by Pyridin silver stain.

d. Regenerative process of the axis cylinder with an increase in number of fibrillae.

e. Sketch illustrating the process of regeneration in which the neurofibrillae from the axis cylinder entered the distal segment following protoplasmic bands through the intervening gap (28 days after operation).

f. Regeneration of the axis cylinder with the formation of the reticulum of the myelin sheath (35 days after operation).

g. The proliferated changes that have taken place in the Schwann sheath nuclei on the third day following severance brought out by hematoxylin and eosin method.

h. Progress of the proliferative change in Schwann sheath cells on the eighth day following severance of the nerve.

i. Wallerian degeneration of the myelin sheaths on the eighth day brought out by Marchi's method.

j. Bridging of the intervening gap with protoplasmic bands arising from Schwann sheath nuclei.

PLATE 3.

Fig. 1.

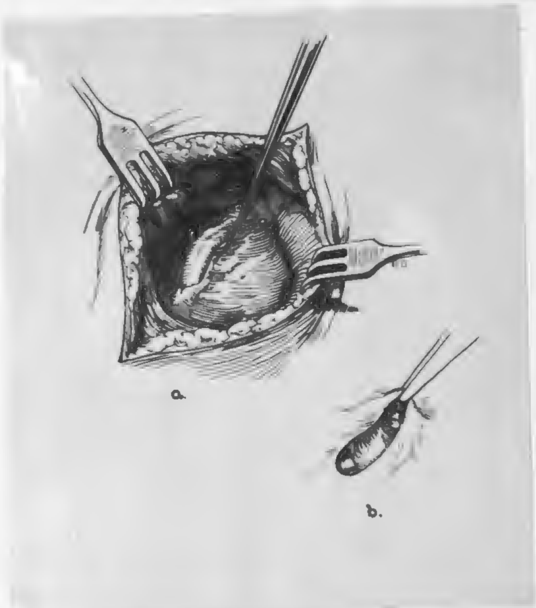
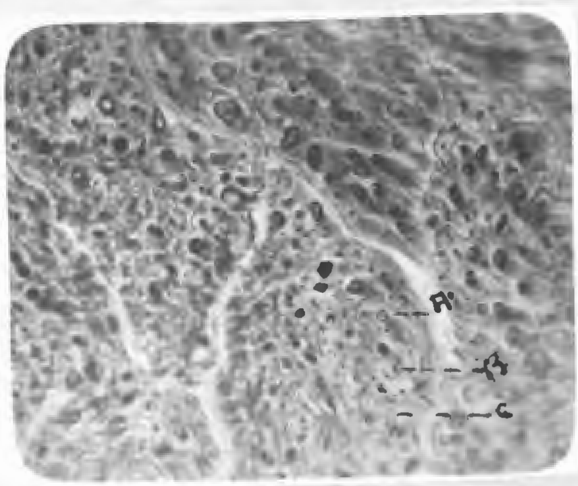


Fig. 2.



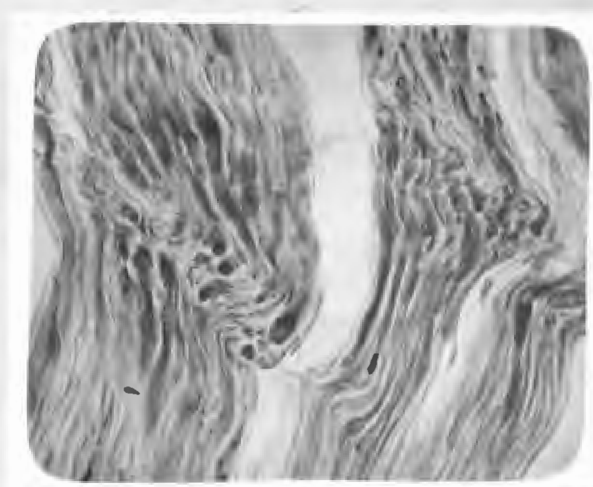


Fig. 3.

Fig. 4.

NERVE SEVERED WITHOUT ANASTOMOSIS

Fig. 1. Technic of dividing and permitting the nerve to fall back into the sheath.

Fig. 2. Photograph of gross specimen B886 L.S., with proximal end to the left. (Actual size). Time after operation 197 days. n, Neuroma.

Fig. 3. Photomicrograph of cross section of distal portion of B886 L.S. (Pyridin silver stain, X500). a, Regenerating medullated axon, b, non-medullated axon, c, neurofibrillae.

Fig. 4. Photomicrograph of longitudinal section of distal portion of B886 L.S. (Pyridin silver stain, X500).

Adson.

PLATE 2.

Fig. 1.

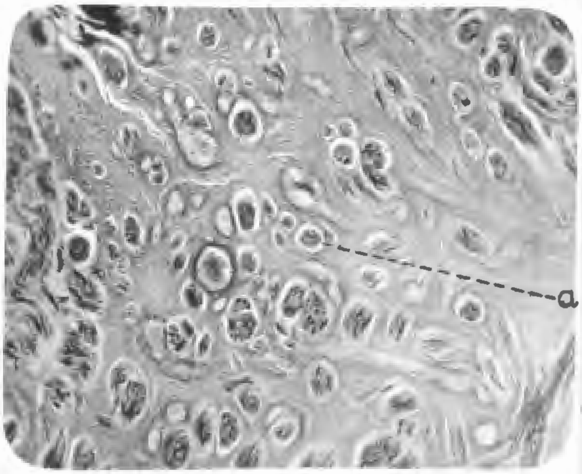


Fig. 2.

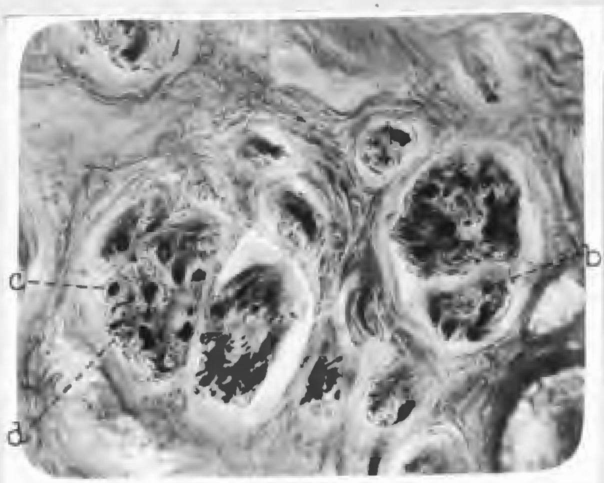


Fig. 3.

FUSION METHOD

Fig. 1. Photograph of gross specimen C14 L.U. with proximal end to the left. (Actual size). Duration of anastomosis 126 days.

Fig. 2. Photomicrograph of cross section of distal portion of C14 L.U. (Pyridin silver stain, X100). a,Bundles of regenerating nerves in scar tissue.

Fig. 3. Photomicrograph of cross section of distal portion of C14 L.U. (Pyridin silver stain, X 500). b,Axon, c,medullated axon, d,neurofibrillae.

PLATE 4.

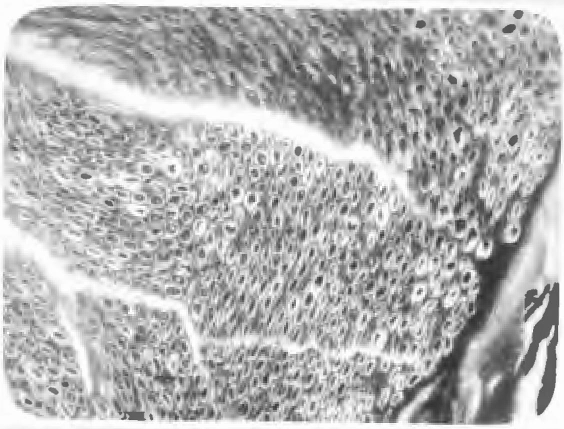


Fig. 1.

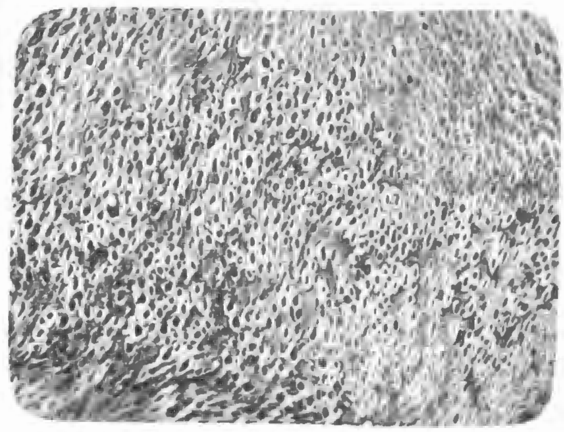


Fig. 2.

ANASTOMOSIS WITH SILK AND FASCIAL COVERING

Fig. 1. Photomicrograph of cross section of B412 R.S. showing the normal medullated axons. (Pyridin silver stain, X150).

Fig. 2. Photomicrograph of cross section of distal portion of B412 L.S. (Pyridin silver stain, X150). Regenerated axons. Duration of anastomosis 529 days. Differs from Fig. 1 in that axons are slightly smaller and surrounded by less myelin.

Adson.

PLATE 5.

Fig. 1.

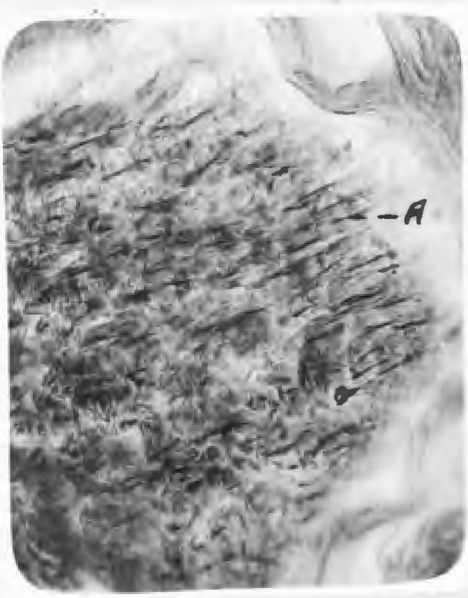


Fig. 2.

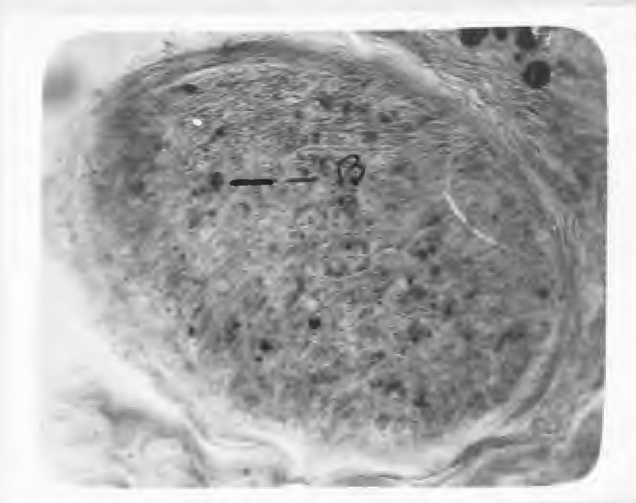


Fig. 3.

FASCIAL TUBULIZATION

Fig. 1. Photograph of gross specimen C342 L.S. (Actual size). Duration of anastomosis 43 days.

Fig. 2. Photomicrograph of longitudinal section of distal portion of C342 L.S. (Pyridin silver stain, X300). a, Regeneration axons without myelin sheath.

Fig. 3. Photomicrograph of cross section of distal portion of C342 L.S. (Marchi method, X150). b, Degenerating myelin.

PLATE 6.

Fig. 1.

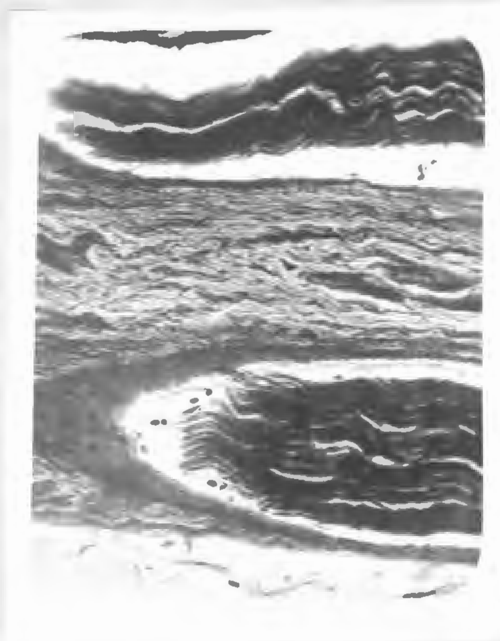


Fig. 2.

Fig. 3.

ANASTOMOSIS WITH SILK AND ANIMAL MEMBRANE COVERING

Fig. 1. Photograph of gross specimen B683 R. U. (Actual size). Duration of anastomosis 328 days.

Fig. 2. Photomicrograph of cross section of distal portion of B683 R. U. (Pyridin silver stain, X100). Regenerating medullated and non-medullated axons.

Fig. 3. Photomicrograph of longitudinal section of distal portion of B683 R. U. (Pyridin silver stain, X100). A high percentage of regeneration.

Fig. 1.

Fig. 2.

Fig. 3.

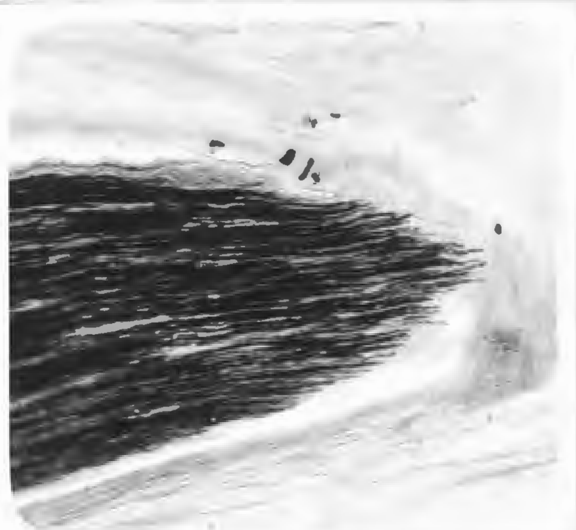
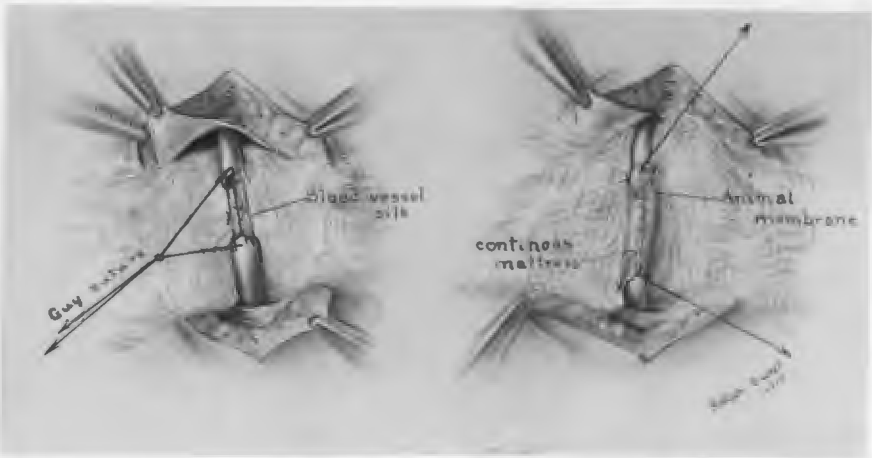


Fig. 4.



ANASTOMOSIS WITH SILK AND ANIMAL MEMBRANE COVERING (Continued)

Fig. 1. Photograph of gross specimen, B810, R. U. (Actual size). Duration of anastomosis 315 days.

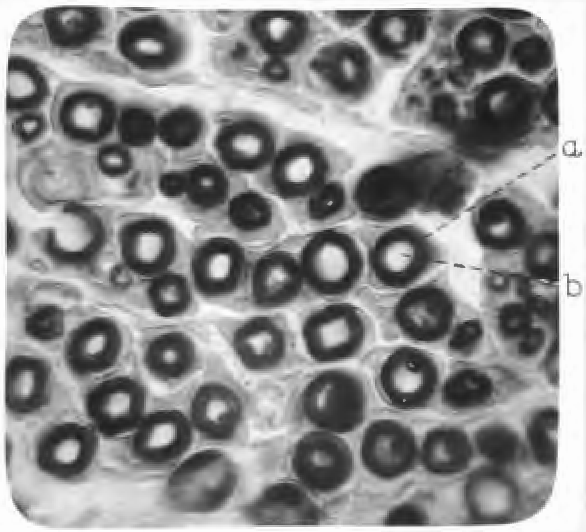
Fig. 2. Photomicrograph of cross section of distal portion of B810 R. U. (Osmic acid stain, X500). The osmic acid has washed into the axis cylinders. Compare the size of axons with Fig. 2, Plate 8, which shows a normal medullated nerve.

Fig. 3. Photomicrograph of longitudinal section of distal portion of B810, R. U. (Osmic acid stain, X60). Regenerated myelin sheaths 315 days after operation.

Fig. 4. Anastomosis with blood vessel silk. The intervening gap and nerve ends covered with a tube of animal membrane.

PLATE 8.

Fig. 1.



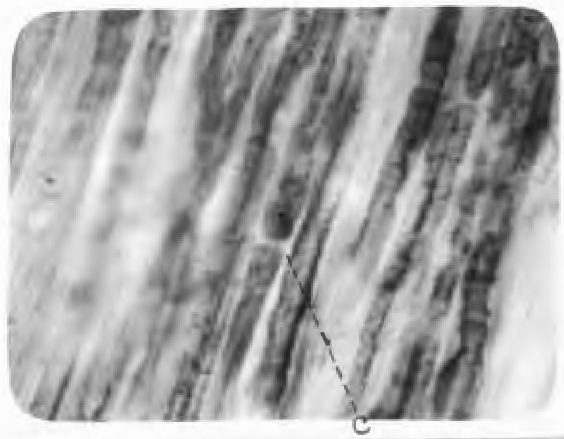


Fig. 3.

Fig. 2.

ANASTOMOSIS WITH SILK AND ANIMAL MEMBRANE COVERING (Continued)

Fig. 1. Phètograph of gross specimen, B911 L. S. (Actual size). Duration of anastomosis 345 days.

Fig. 2. Photomicrograph of cross section of B918 L. S., a normal sciatic nerve. (Osmic acid stain, X500). a, Myelin sheaths, b, axon .

Fig. 3. Photomicrograph of longitudinal section of B911 L. S. (Osmic acid stain, X500). A regenerated medullated axon showing deposit of myelin and c, nodes of Ranvier.

PLATE 9.

Fig. 1.

Fig. 2.

Fig. 3.

VEIN TUBULIZATION

Fig. 1. Photograph of gross specimen C351 L. U. (Actual size). Duration of anastomosis 42 days.

Fig. 2. Photomicrograph of cross section of distal portion of C351 L. U. (Pyridin silver stain, X500). Shows regeneration with several non-medullated axons with neurofibrillae in one band of protoplasm.

Fig. 3. Photomicrograph of longitudinal section of distal portion of C351 L. U. (Pyridin silver stain, X100). Shows regenerated axons which stained black.

PLATE 10.

Fig. 1.

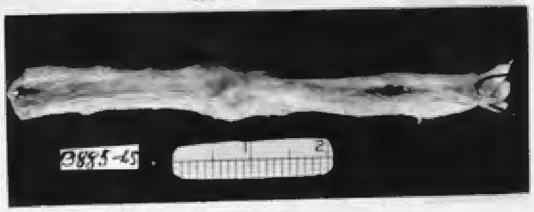


Fig. 2.

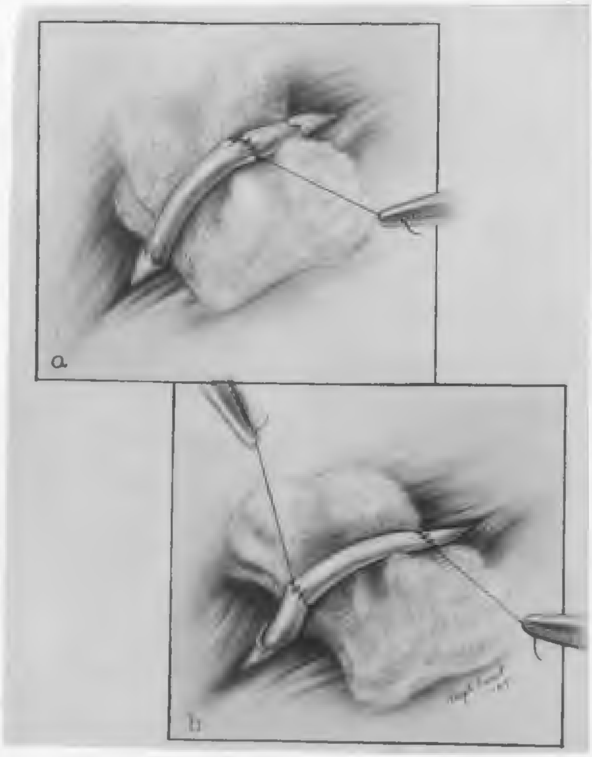
ANASTOMOSIS WITH BLOOD VESSEL SILK WITHOUT COVERING

Fig. 1. Photograph of gross specimen B885 L. S. (Actual size). Duration of anastomosis 245 days.

Fig. 2. Photomicrograph of cross section of B885 L. S. (Pyridin silver stain, X500). Complete regeneration. a, medullated axon, b, non-medullated axon.

PLATE 11.

Fig. 2.



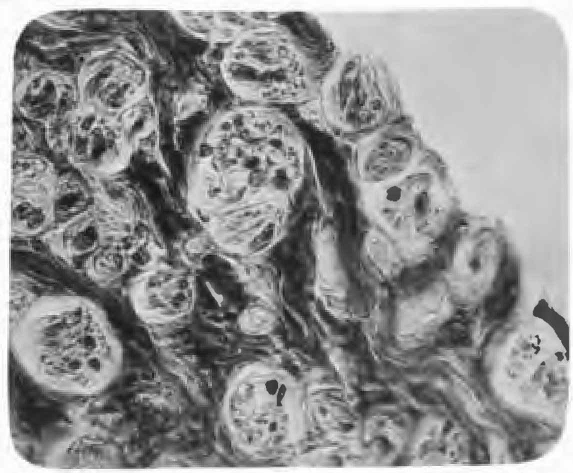


Fig. 1.

Fig. 3.

AUTOGENOUS TRANSPLANTS

Fig. 1. Method used in dividing nerve and inserting the same section as an autogenous nerve transplant.

Fig. 2. Photograph of gross specimen B669 L. S. (Actual size). Duration of anastomosis 214 days.

Fig. 3. Photomicrograph of cross section of transplant, B669 L. S. (Pyridin silver stain, X500). Shows the method of regeneration - bundles containing regenerating axons with neurofibrillae surrounded by dense fibrous tissue.

PLATE 12.

Fig. 1.

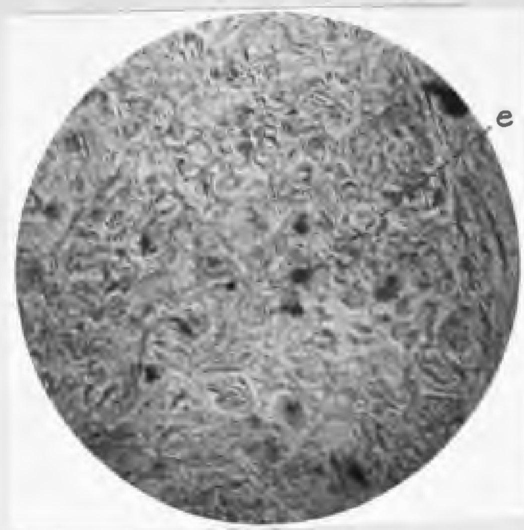


Fig. 3.

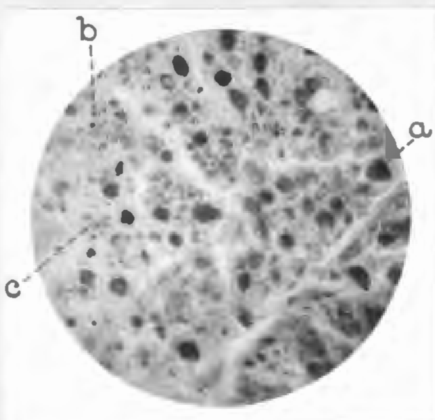


Fig. 2.

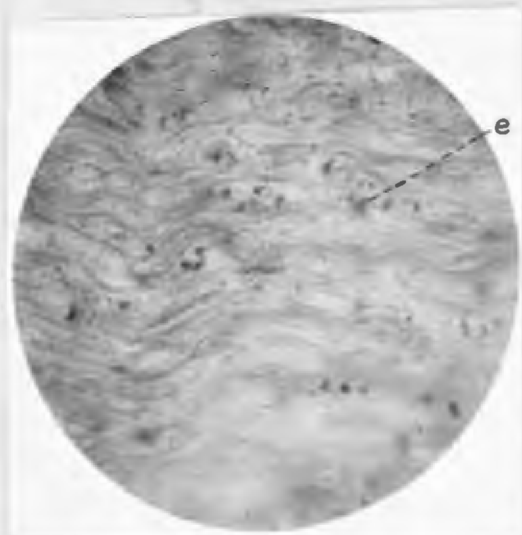


Fig. 4.

NERVES CRUSHED WITH FORCEPS

Fig. 1. Photograph of gross specimen C330 L. S. (Actual size). Time after operation 42 days. a, Area crushed with forceps.

Fig. 2. Photomicrograph of cross section of distal portion of C330 L. S. (Pyridin silver stain, X300). Early regeneration. a, Early deposit of myelin about axon, b, non-medullated axons, c, neurofibrillae.

Figs. 3 and 4. Photomicrographs of cross and longitudinal sections of distal portion of C330 L. S. (Marchi method, X300). Still shows presence of e, degenerated myelin, while Fig. 2 shows the regeneration that was going on at the same time.

PLATE 13.

Fig. 1.

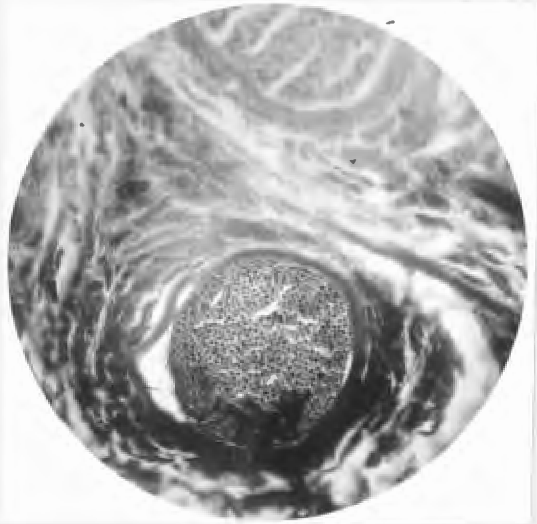


Fig. 3.

Fig. 2.

NERVES CRUSHED WITH FORCEPS (Continued)

Fig. 1. Photograph of gross specimen of distal portion of C336 L. U. (Actual size). Time after operation 46 days.

Fig. 2. Photomicrograph of cross section of distal portion of C336 L. U. (Pyridin silver method, X60). Regenerating axons stained black.

Fig. 3. Photomicrograph of longitudinal section of distal portion of C336 L. U. (Pyridin silver stain, X100). Regenerating black stained axons stained black.

PLATE 14.

Fig. 1.

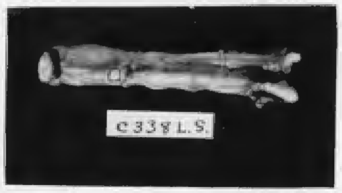
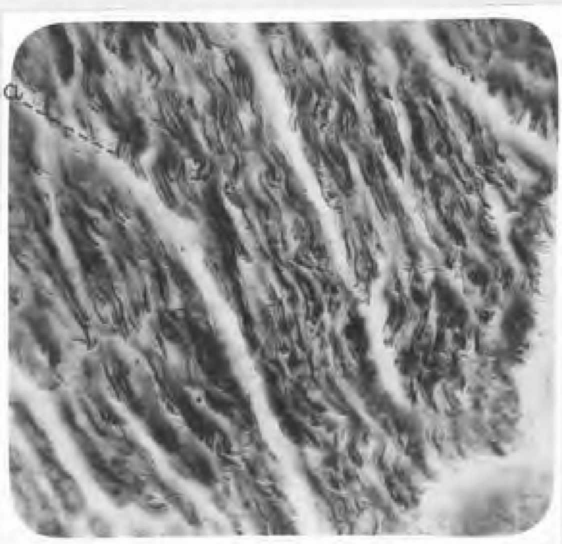


Fig. 2.



NERVES LIGATED WITH CATGUT

Fig. 1. Photograph of gross specimen C338 L. S. 46 days after operation. (Actual size). a, Area where nerve was ligated.

Fig. 2. Photomicrograph of longitudinal section of distal portion of C338 L. S. (Pyridin silver stain, X200). a, Regenerating axone.

PLATE 15.

Fig. 1.

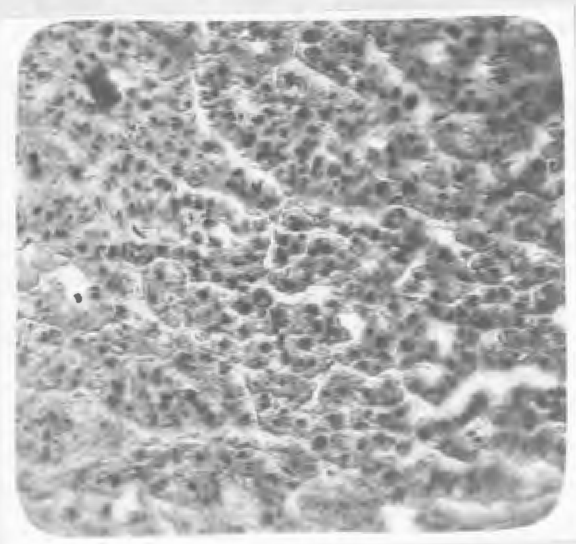


Fig. 2.

NERVES LIGATED WITH SILK

Fig. 1. Photograph of gross specimen of C337 L. S. 46 days following operation. (Actual size).

Fig. 2. Photomicrograph of cross section of distal portion of C337 L. S. (Pyridin silver stain, X240). Early regeneration in protoplasmic bands. Black areas are the black-stained non-medullated axons.

PLATE 16.

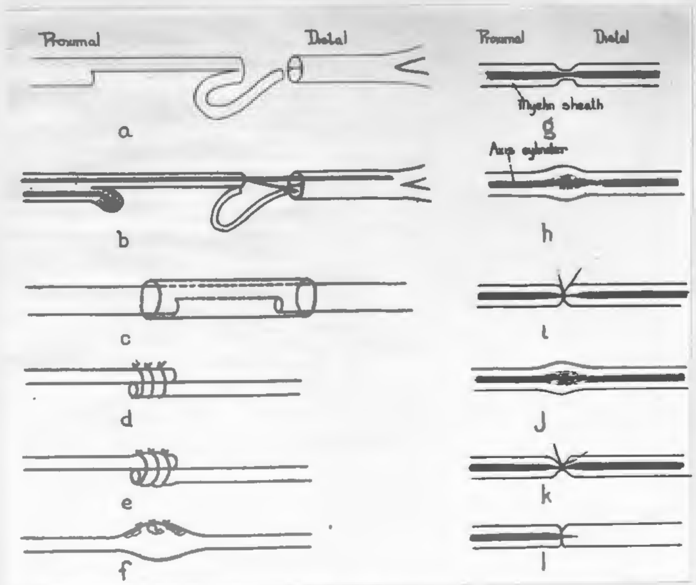


Fig. 1.

Fig. 1. Diagrams illustrating the process of regeneration under the various operations. a, Nerve anastomosis with a plastic flap turning down half of the sciatic nerve and anastomosing the flap to the distal segment, b, results of plastic operation; neuroma of the inner portion of the sciatic nerve, atrophy of the plastic flap and partial regeneration with axons entering the external and internal portions of the distal segment, c, operative procedure which was followed by regeneration over a 4 cm. gap; inner portion of sciatic nerve resected, the severed end being held in place by the external portion of nerve and both portions protected by a tube of fascia, d, e, f, the Feiss method; nerve ends overlapped for a distance of 4 mm. and ligated with silk, the result being the formation of a very large neuroma, the cutting through of the silk ligatures and partial regeneration, g, h, gentle crushing of nerve with forceps resulting in the formation of a small neuroma and good regeneration; i, j, ligation of nerve with catgut resulting in the formation of a neuroma with good but slower regeneration than when nerve was cut; k, l, ligation with silk resulting in a failure to regenerate unless the ligature is tied tightly which destroys the sheath and produces partial regeneration.

PLATE 17.

Fig. 1.

Fig. 3.

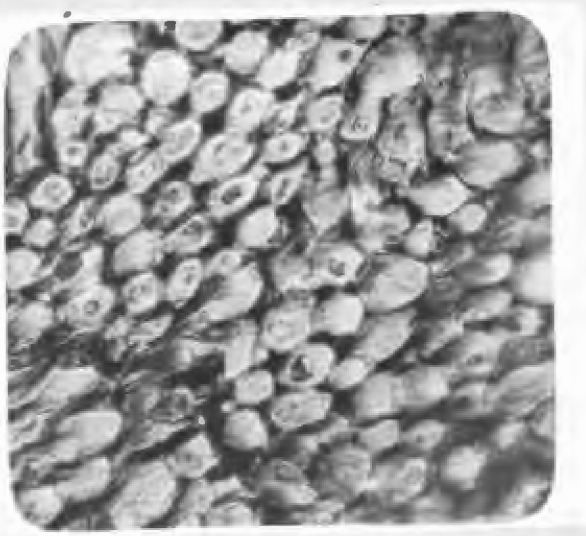


Fig. 4.

Fig. 2.

DEGENERATIVE STAGES

Fig. 1. Three days' degeneration. Photograph of gross specimens of B743 R. U. and B743 L. U. 3 days after operation, an anastomosis with silk with covering of animal membrane. (Actual size).

Fig. 2. Three days' degeneration. Photomicrograph of cross section of distal portion of B743 R. U. (Pyridin silver stain, X500). Shows all stages of degeneration in the axis cylinders from the c, dark resistant axons to absolute destruction of the axon. a, Axon, b, myelin sheath.

Fig. 3. Eleven days' degeneration. Photograph of gross specimen, B908 L. S. 11 days after operation in which ends were overlapped and ligated. (Actual size).

Fig. 4. Eleven days' degeneration. Photomicrograph of cross section of distal portion of B908 L. S. showing stages of degeneration in the myelin as well as the axons. (Pyridin silver stain, X500).

PLATE 18.

Fig. 1.

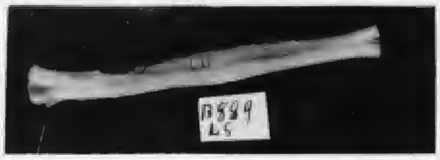
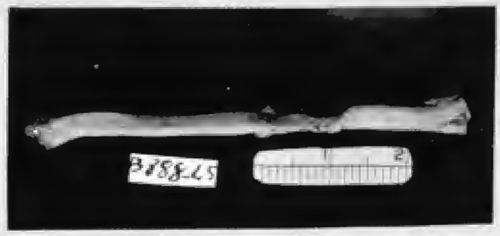


Fig. 3.



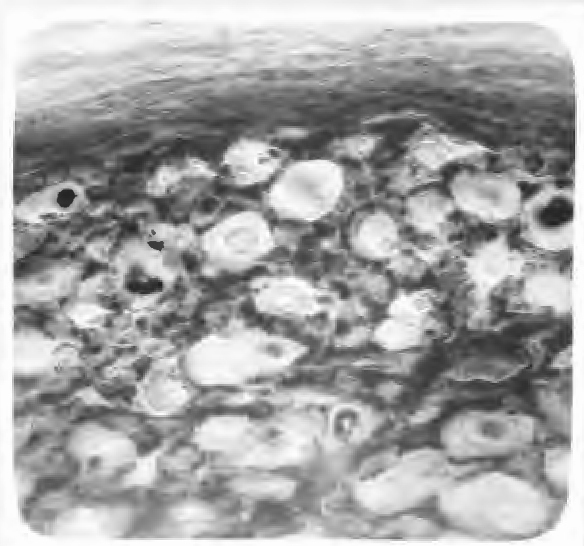


Fig. 2.

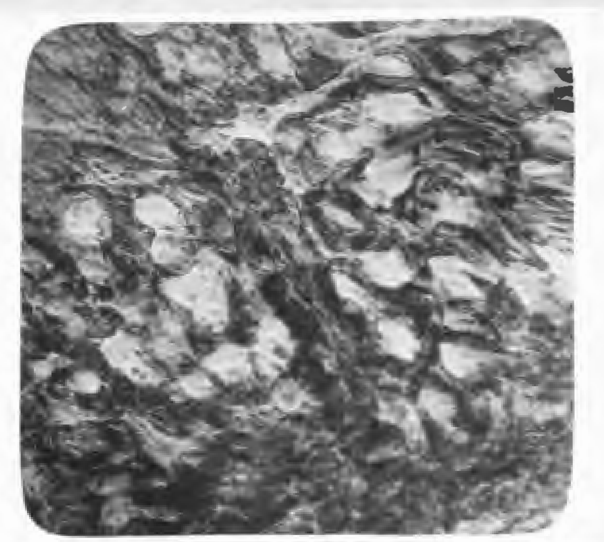


Fig. 4.

DEGENERATIVE STAGES (Continued)

Fig. 1. Eighteen days' degeneration. Photograph of gross specimen, B889 L. S. 18 days after nerve was crushed with forceps. (Actual size). a, Area crushed.

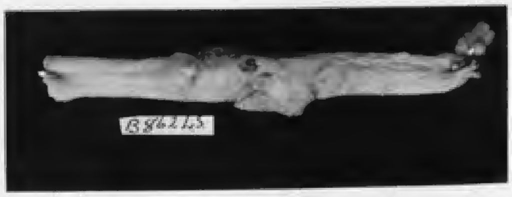
Fig. 2. Eighteen days' degeneration. Photomicrograph of cross section of distal portion of B889 L. S. showing advanced stages in the degeneration of axons and the myelin sheaths. (Pyridin silver stain, X500). Only three resistant axons in the field.

Fig. 3. Twenty-six days' degeneration. Photograph of gross specimen, B888 L. S., 26 days after nerve was severed. (Actual size).

Fig. 4. Twenty-six days' degeneration. Photomicrograph of cross section of distal portion of B888 L. S. showing complete destruction of axis cylinders with marked destruction of myelin. (Pyridin silver stain, X500).

PLATE 19.

Fig. 1.



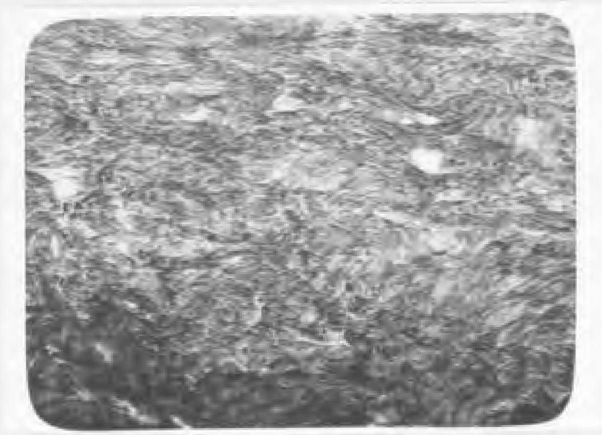


Fig. 2.

DEGENERATIVE STAGES (Continued)

Fig. 1. Thirty-seven days' degeneration. Photograph of gross specimen, B862, L. S. 37 days after nerve was severed. (Actual size).

Fig. 2. Thirty-seven days' regeneration. Photomicrograph of cross section of distal portion of B862L.S.(Pyridin silver stain, X240). No axons present. Marked increase in the proteplasm and apparent fibrous tissue with only three resistant areas of myelin (Very probably three large fat droplets).

Adson.

PLATE 20.

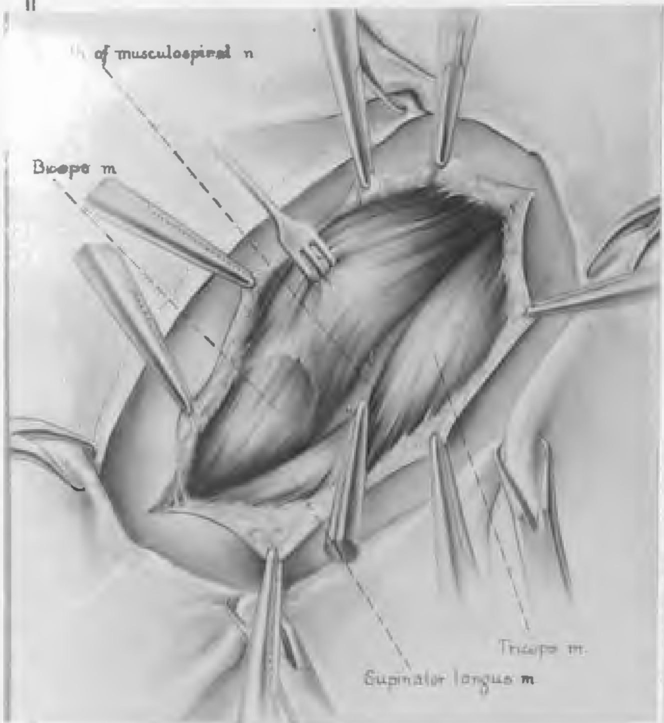


Fig. 1.

Fig.2.

END-TO-END ANASTOMOSIS

Fig. 1. Exposure of left musculospiral nerve.

Fig. 2. Anastomosis of musculospiral nerve with silk. Stitches placed in the epineurium.

PLATE 21.

Fig. 1.

Fig. 2.

Fig. 3.

END-TO-END ANASTOMOSIS WITH SILK AND FASCIAL COVERING

Fig. 1. Incision to expose musculospiral nerve carried upward from antecubital space along musculospiral groove.

Fig. 2. Anatomical relations of proximal and distal neuromata of musculospiral nerve following severance at the time of fracture of lower third of humerus.

Fig. 3. Exposure of distal neuroma and the relations of the callus which followed the fracture of the humerus.

PLATE 22.

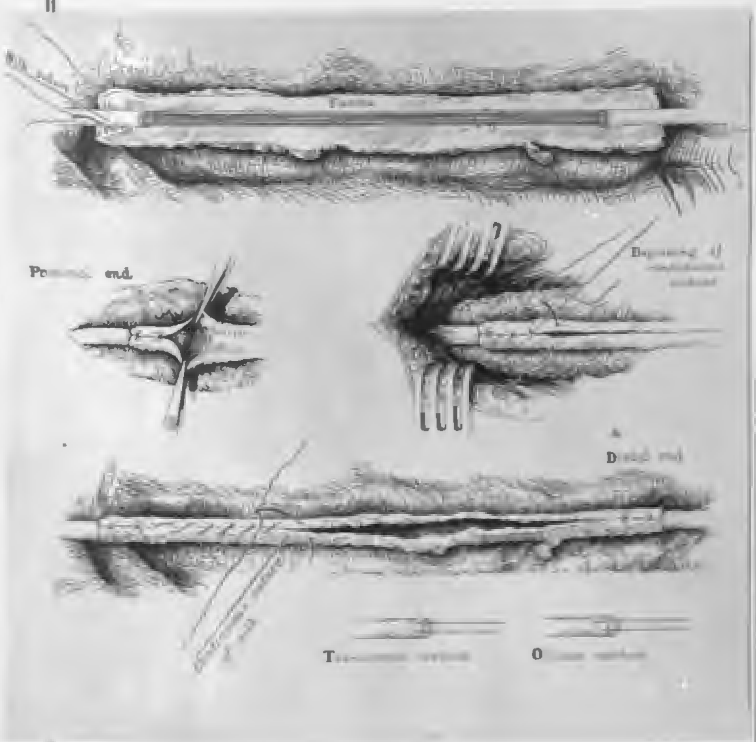


Fig. 1.

Fig. 2.

END-TO-END ANASTOMOSIS WITH SILK AND FASCIAL COVERING (Continued)

Fig. 1. Method of anastomosing with silk. Various steps in covering the cylinder of silk with fascia.

Fig. 2. Removal of fascia from thigh. Fascia is used to make a covering about the cylinder of silk in the anastomosis of the musculospiral nerve.

PLATE 23.

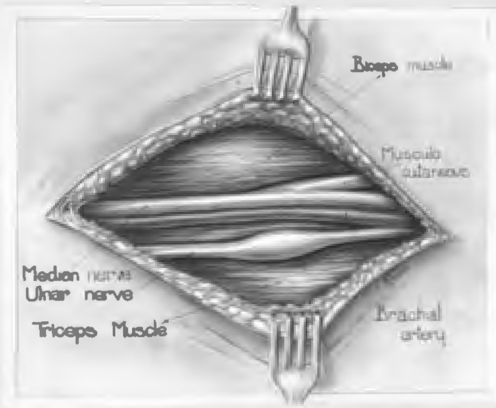


Fig. 1.

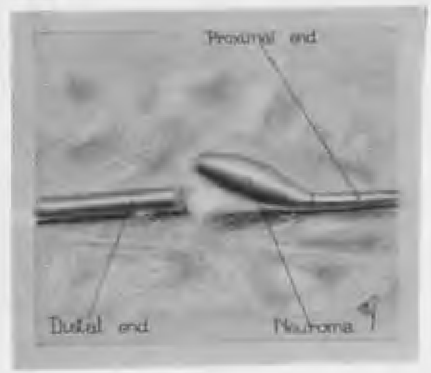


Fig. 2.

END-TO-END ANASTOMOSIS WITH SILK AND FASCIAL COVERING (Continued)

Fig. 1 (202189). Exposure of ulnar nerve with a large neuroma due to trauma without severance xxxxxxxxxxx in right upper brachial region.

Fig. 2 (202189). Resection of neuroma previous to anastomosis.

PLATE 24.

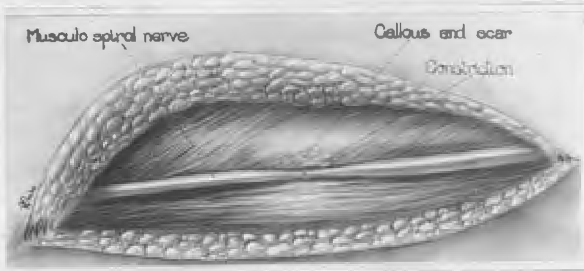


Fig. 1.

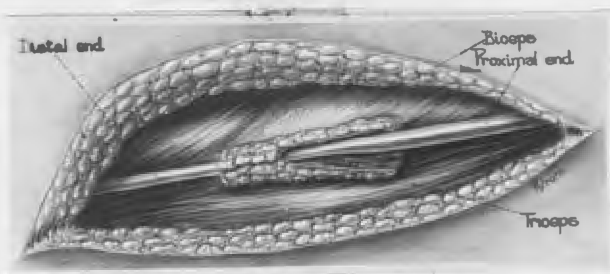


Fig. 2.

LIBERATING NERVES FROM CONSTRICTING SCAR TISSUE

Fig. 1. Exposure of left musculo-spiral nerve which is constricted by an exuberant callus and scar without complete destruction.

Fig. 2. Covering the constricted musculo-spiral nerve with a fascial flap to avoid further constriction.

PLATE 25.

END-TO-END ANASTOMOSIS WITH VEIN COVERING

Anastomosis of proximal end of spiral accessory nerve to distal end of facial nerve.

Key:-

LPT -- Left Posterior Tibial
RPT -- Right " "
LU -- Left Ulnar
RU -- Right Ulnar
LF -- Left Femoral
RF -- Right Femoral
LS -- Left Sciatic
RS -- Right Sciatic

+ -- Positive findings

- -- Not reported

0 -- Negative findings

PROTOCALS

Dog Number	Experiment	Date of Operation	Death-Date and Cause	Duration of Anastomosis (days)	Nerves	TYPES OF OPERATION	Specimen saved	REGENERATION (Per cent) Anatomical	Electrical	Histological
B382	81	2-19-16	5-22-16 poisoned	103	LPT	anastomosis, silk, no covering	+	50	-	60
					RPT	" " facial "	+	100	-	80
		3-28-16		56	LU	" " bone tube "	+	0	-	?
					RU	" " vein "	+	50	-	90
B383	83	2-10-16	8-31-16 sacrificed	203	LPT	" " facial covering	+	100	100	70
					RF	severed, without anastomosis	+	100	100	80
					LF	overlapped and ligated with silk	+	100	100	70
					RPT	severed, without anastomosis	+	100	100	75
B387	91	2-14-16	2-25-16 distemper	11	LPT	anastomosis with silk, vein covering	Specimens taken but not stained.			
					RPT	" " " facial "				
					LF	severed, without anastomosis				
					RF	overlapped and ligated with silk				
B249	92	2-15-16	9-11-16 sacrificed	209	LPT	anastomosis with silk, vein covering	+	100	100	100
					RPT	" " " , no "	+	100	100	100
					RF	overlapped and ligated with silk	+	50	50	60
					LF	severed, without anastomosis	+	50	50	40
			3-27-16	168	LU	anastomosis with silk, fiber tube cover.	+	0	0	0
					RU	" " " , vein covering	+	100	100	-
B248	94	2-16-16	5- 9-16 killed in fight	83	LPT	anastomosis with silk, vein covering	+	100	-	85
					RPT	" " " , facial "	+	100	-	95
					LF	severed, without anastomosis	+	100	-	-
					RF	overlapped, ligated with silk	+	100	-	85
			3-30-16	39	LU	anastomosis with silk, bone tube cover.	0	-	-	-
					RU	auto-transplant	0	-	-	-

Continued(2)

B340	105	2-22-16	3- 4-16 Died-cause?	33	LPT	anastomosis with silk, vein covering				
					RPT	" " " ,no "	Specimens taken but not stained			
					RF	severed, without anastomosis				
					LF	crushed, without anastomosis				
B341	107	2-23-16	6-29-16 sacrificed	123	LPT	anastomosis with silk, vein covering	+	50	-	50
					RPT	" " " ,facial "	+	100	-	50
					LF	severed, without anastomosis	+	25	-	?
					RF	overlapped and ligated with silk	+	100	-	?
			3-29-16	0	LU	anastomosis with silk, bone tube cover.	+	0	-	0
					RU	" " " " " "	+	0	-	0
B331	114	2-29-16	9- 6-16 sacrificed	187	LPT	auto-transplant, vein covering	+	100	100	85
					RPT	" " ,facial "	+	75	75	90
					RF	severed, without anastomosis	+	100	100	90
					LF	overlapped, ligated with silk	+	100	100	65
B397	116	3-1 -16	Lost at farm	-	LPT	auto-transplant, facial covering	0	-	-	-
					RPT	" " " "	0	-	-	-
					LF	crushed, without anastomosis	0	-	-	-
					RF	overlapped and ligated with silk	0	-	-	-
B400	126	3-16-16	5-20-16 Died-mange	65	LS	anastomosis with silk, facial covering	+	50	-	75
B401	131	3- 7-16	5-18-16 sacrificed	71	LS	anastomosis, silk, facial covering	+	25	-	60
					LF	crushed, without anastomosis	+	25	-	50
					RF	nerve ligated with catgut without anas.	+	25	-	20
B402	132	3-18-16	5-21-16 sacrificed	73	LS	anastomosis, silk, facial covering	+	75	-	90
					LF	crushed, without anastomosis	0	-	-	-
					RF	overlapped and ligated with silk	+	50	-	50
B403	135	3-11-16	3-11-16 anasthetic	0	-	operation not completed	No specimen			

Continued (3)

B409	150	3-14-16	5-15-17	428	RU	anastomosis with silk facial covering	0	Cases B409 & B410		
			sacrificed		LU	" " " " "	0	are not included in counts.		
		12-4-16			LS	" " " " "	0	On account of error		
								in labeling		
B410	151	3-14-16	3-11-17	361	LS	anastomosis with silk fascial covering	+	-	-	100
		4- 2-16	sacrificed	342	LU	" " " g.pig intest. "	+	25	-	15
					RU	" " " ,bone tube covering	+	-	-	15
		12-13-16		88	LU	" " " animal membrane "	0	-	-	-
					RU	" " " " " "	0	-	-	-
B411	152	4-14-16	10-23-17	544	LS	fascial flap with plastic anastomosis	+	25	25	70
		12-8-16	sacrificed	320	RU	anas.with silk,animal memb.cover. gap 3mm	+	100	100	90
					LU	" " " " " " "12 "	+	55	85	80
B412	153	3-14-16	8-26-17	529	LS	fascial flap with plastic anastomosis	+	-	-	100
		12-11-16	sacrificed	286	RU	anas.with silk,animal memb.cover.gap 10mm	+	-	-	75
					LU	" " " " " " " 12"	+	-	-	60
B408	147	3-14-16	6-13-17	456	LS	plastic nerve flap,nerve reoperated	+	-	-	?
	614	10-10-16	sacrificed	276	RU	anas. with silk,no covering,no gap	+	100	100	60
					LU	" " " " " " "	+	100	100	90
	675	11-15-16		241	LS	" " " animal memb.cover.gap6cm	+	0	0	0?
B379	148	3-14-16	5-29-17	441	LS	plastic nerve flap,nerve reoperated	+	40	40	50
	619	10-19-16	sacrificed	252	LU	anastomosis with silk,fasc.cover.gap7mm	+	100	100	90
					RU	" " " ,no cover. " " "	+	60	60	85
	677	11-18-16		223	LS	" " ",animal memb.cover				
						gap 4cm. part of nerve resected Int.Pop	+	100	100	90
						Ext.Pop	+	90	90	80
B599	623	10-24-16	3-11-17	168	RU	anastomosis with chr.gut no cover no gap	+	specimens destroyed		
			sacrificed		LU	" " " " fascial cover.	+			
B619	643	10-26-16	dog lost at		RU	anas.chr.gut gap 4mm no covering	0	-	-	-
			farm		LU	" " " " " fascial covering	0	-	-	-
		3- 3-17			LS	" with blood vessel silk,no gap	0	-	-	-

Adson-V.

Continued (4)

B631	658	11-3-16	1-25-17	83	RU	overlapped, ligated with	chr.gut 3 strands	+	50	50	40
			sacrificed		LU	" " "	silk 3 strands	+	75	75	75
					RF	" " "	chr.gut 3 strands	+	0	0	0
					LF	" " "	silk 3 strands	+	50	50	40
B634	661	11-6-16	1 3-17	58	RU	" " "	chr.gut 3 strands	+	100	100	90
			sacrificed		LU	" " "	silk, 3 strands	+	75	75	75
					RF	" " "	chr. 3 strands	+	100	100	80
					LF	" " "	silk 3 strands	+	50	50	50
B641	672	11-13-16	12-28-16	45	RU	" " "	chr.gut 2 strands	+	-	-	70
			died-bronchial		LU	" " "	silk, 4 strands	+	-	-	40
			pneumonia		RF	" " "	chr.gut 3 strands	0	-	-	-
					LF	" " "	silk 3 strands	0	-	-	-
B646	679	11-20-16	12-18-16	28	RU	" " "	chr.gut 3 strands	+	-	-	-
			killed in fight		LU	" " "	silk 3 strands	+	-	-	-
					LS	" " "	silk 3 strands	+	-	-	-
					RF	" " "	chr. gut 3 strands	+	-	-	-
B648	681	11-22-16	12-26-16	34	RU	" " "	chr.gut 3 strands	+	-	-	-
			died-distemper		LU	" " "	silk 3 strands	+	-	-	25
					LF	" " "	silk 2 strands	0	-	-	-
					RF	" " "	chr.gut 2 strands	0	-	-	-
B653	694	12- 1-16	1- 6-17	36	RU	" " "	chr.gut 3 strands	+	50	50	-
			killed in fight		LU	" " "	silk 3 strand	+	100	100	-
B669	712	12-15-16	10-25-17	250	RU	anas.with silk,animal memb.cover.gap 10mm		+	75	75	80
			sacrificed		LU	" " " " " " " 12 "		+	75	75	25
		3-21-17		214	LS	auto-transplant 25mm blood vessel silk		+	95	95	95
B671	714	12-18-16	6-19-17	183	RU	anas.with silk,animal memb. cover. gap 10mm.		+	25	25	25
			sacrificed		LU	" " " " " " " "		+	20	20	-
		3-14-17		97	LS	auto-transplant, 25mm blood vessel silk		+	75	75	25

Continued (5)

B677	721	12-22-16	2-27- 18	420	RU	anas.with silk,animal memb.cover gap 10mm	+	95	95	-
			sacrificed		LU	" " " " " " " 2mm	+	90	90	-
		3-14-17		350	LS	" " blood vessel silk,no gap,no cover.	+	100	100	-
B683	733	12-27-16	10-26-17	328	RU	anas.with silk,animal memb.cover.gap 10mm	+	85	100	-
			died-chronic nephritis		LU	" " " " " " " 5mm	+	100	-	-
B686	737	12-29-16	12-30-16	1	RU	anas.with silk,animal memb.cover.gap 10mm	0	-	-	-
			died septic pneumonia		LU	" " " " " " " 15mm	0	-	-	-
B697	8	1- 5-17	1-25-17	20	RU	anas.with silk,animal memb.cover.gap 20mm	0	-	-	-
					LU	" " " " " " " "	+	-	-	-
B705	16	1- 8-17	4-26-17	108	RU	" " " " " " " 12mm	+	-	-	-
			sacrificed		LU	" " " " " " " "	+	-	-	95
B713	24	1-10-17	2- 3-17	22	RU	" " " " " " " "	+	-	-	-
			died-distemper		LU	" " c " " " " " 20mm	+	-	-	-
B726	37	1-15-17	2- 9-17	40	RU	" " " " " " " 15mm	+	-	-	20
			died distemper		LU	" " " " " " " 17mm	+	-	-	-
B727	38	1-17-17	5- 8-17	101	RU	anas. with blood vessel silk a.memb.gap 15mm	+	75	75	90
			sacrificed		LU	" " " " " " " " 10"	+	75	75	90
B728	39	1-19-17	1-31-17	12	RU	" " " " " " " " 3mm	+	0	0	deg.
			died-distemper		LU	" " " " " " " " 5mm	+	0	0	deg.
B738	49	1-26-17	4-14-17	78	RU	" " " " " " " " 3mm	+	0	0	-
			died-distemper		LU	" " " " " " " " 5mm	+	0	0	-
B743	54	1-29-17	2- 3-17	3	RU	" " " " " " " no gap	+	-	-	deg.
			died-distemper		LU	" " " " " " " " "	+	-	-	deg.

Continued (6)

B786	116	2-17-17	9- 6-17 died-cause?	200	RU LU	anas.blood vessel silk,a.memb.cover.no gap " with black silk " " " " "	+ +	- -	- -	80 90
B825	186	3- 3-17	4-13-17 killed in fight	40	LU RS	severed,without anastomosis(a septic) " " " (septic)	+ +	- -	- -	- -
B826	187	3- 3-17	lost at farm		LU RS	severed,without anastomosis (aseptic) " " " (septic)	0 0	- -	- -	- -
B860	228	3-14-17	anesthetic death							
B861	229	3-14-17	6-19-17 sacrificed	97	LU LS	" " " (aseptic) " " " (")	+ +	50 50	100 50	75 50
B862	230	3-14-17	4-20-17 died-distemper	37	LU LS	" " " (septic) " " " (")	+ +	- -	- -	20 deg.
B863	231	3-14-17	5-15-17 sacrificed	62	LU LS	" " " (septic) " " " (")	+ +	25 50	25 50	25 40
B885	268	3-21-17	10-25-17 sacrificed	245	LS	anas.with blood vessel silk, no gap no cover. in the presence of serious inflammation	+	95	95	100
B886	269	3-21-17	10- 4-17 sacrificed	197	LU LS	crushed,without anastomosis (aseptic) divided, " " (")	+ +	100 60	100 60	100 70
B888	270	3-21-17	4-16-17 died-distemper	26	LS LU	divided, " " (septic) crushed, " " (septic)	+ +	- -	- -	deg. -
B889	271	3-21-17	4 9-17 died-bronchial pneumonia	18	LS LU	crushed, " " (septic) divided, " " (septic)	+ +	- -	- -	deg. deg.
B906	297	3-28-17	4-16-17	18	LS	anas.with blood vessel silk,no cover.gap 25mm	+	specimen not stained		
B907	298	3-28-17	7- 7-17 killed in fight	101	LS	" " " " " " " " "		no specimen		

Continued (7)

B908	299	3-28-17	4- 8-17 died-bronchial pneumonia	11	LS	overlapped and ligated,black silk 3 strands	+	-	-	deg.
B909	300	3-28-17	4-14-17 died-cause?	7	LS	" " " silk 3 strands	0	-	-	-
B910	301	3-28-17	4-12-17 died bronchial pneumonia	15	LU	severed, without anastomosis	+	-	-	-
					LS	crushed, " "	0	-	-	-
B911	302	3-28-17	2-28-18 sacrificed	345	LU	severed, " "	+	20	20	100
					LS	" " "	+	25	25	100
C13	437	6- 5-17	7- 7-17 died-distemper	32	LU	anas.blood vessel silk,a.memb.gap 5mm	0	-	-	-
					RU	overlapped and ligated,silk 3 strands	0	-	-	-
C14	438	6- 5-17	10-11-17 sacrificed	126	LU	overlapped and ligated,silk 3 strands	+	75	75	65
					RU	" " " " " "	+	90	90	90
B810	456	6-26-17	4-16-18 sacrificed	305	RU	anas.blood vessel silk, gap 15mm	+	95	95	-
					LU	overlapped and ligated, silk 3 strands	+	60	0	80
B811	457	6-26-17	10-4-17 sacrificed	100	RU	anas.blood vessel silk,a.memb. gap 12mm	+	100	100	90
					LU	overlapped and ligated, silk 3 strands	+	60	60	80
C328	122	2-27-18	4-16-18 sacrificed	49	LS	crushed, without anastomosis	+	85	85	85
C329	123	2-27-18	4-16-18 sacrificed	49	LS	" " "	+	-	25	95
C330	124	2-27-18	4-16-18 sacrificed	49	LS	" " "	+	60?	80	90
C334	128	2-28-18	4-16-18	48	LS	overlapped and ligated,silk 3 strands	+	?	0	10?
C335	129	3- 1-18	3-24-18 died-distemper	24	LS	crushed, without anastomosis	+	-	-	60
					LU	" " "	+	-	-	25

Continued (8) Adson-IX.

C336	130	3-1 -18	4- 16-18 sacrificed	46	LS	crushed, without anastomosis	+	?	0	100
					LU	" " "	+	?	20	90
C337	131	3- 1-18	4-16-18 sacrificed	46	LS	" " "	+	0	0	100
C338	132	3- 1-18	4-16-18 sacrificed	46	LS	" " "	+	?	30	100
C341	135	3- 4-18	3-24-18 died-pneumonia	20	LS	auto-transplant , 35mm	+	-	-	10
					LU	anas.fascial tubulization ,gap 12mm(Lewis&Kirk)	+	-	-	-
C342	136	3- 5-18	4-16-18 sacrificed	43	LS	fascial tubulization,no gap " "	+	?	0	90
					LU	" " " " " "	+	?	0	100
C343	137	3-5-18	3-29-18 sacrificed	24	LS	fascial tubulization,gap 12mm x 2mm(Lewis & Kirk)	+	-	-	0
					LU	" " " 2mm x 1mm " "	+	-	-	85
C344	139	3- 6-18	3-28-18 died-cause?	22	LS	" " " 10mml.5mm " "	+	-	-	-
					LU	" " " 4mm x 1mm " "	0	-	-	-
C345	140	3- 6-18	4-16-18 sacrificed	42	LS	vein " " 15 x 1.5mm (Corbett)	+	-	0	0
					LU	" " " 4mm x 1mm "	+	30	45	85
C351	146	3- 6-18	4-16-18 sacrificed	42	LS	" " " 5mm x 1.5mm "	+	?	0	95
					LU	" " " 3mm x 1mm "	+	?	0	100
C352	147	3- 7-18	4- 3-18 died-distemper	27	LS	" " " 10mm x 1.5mm "	+	-	-	-
					LU	" " " 2mm x 1mm "	+	-	-	100

Adson-X.

SUMMARY OF RESULTS FOR EACH TYPE OF OPERATION

Dog Number	Duration of Anastomosis (days)	Nerves Operated	Distance between anastomosed ends: Gap	Distance between anastomosed ends: Diameter of nerve	Regeneration (per cent): Anatomical	Regeneration (per cent): Electrical	Regeneration (per cent): Histological
		PLASTIC OPERATIONS - the splitting and turning of flaps.					
B379	441	LS	-	-	40	-	85
B379	223	LS	4cm	1mm	95	-	80
B412	557	LS	-	-	-	-	-
B411	544	LS	-	-	-	-	-
Total 4 cases Avg.441							
		FUSION METHOD - overlapping and ligating with silk					
B383	203	LF	0	-	100	-	70
B249	209	RF	0	-	50	-	60
B248	83	RF	-	-	50	-	85
B341	123	RF	0	-	100	-	?
B331	187	LF	0	-	100	-	65
B402	73	RF	0	-	50	-	50
C334	46	LS	-	-	?	0	10
B631	83	LU	0	-	75	75	75
B631	83	LF	0	-	50	50	40
B634	58	LU	0	-	75	75	75
B634	58	LF	0	-	50	50	50
B653	36	LU	0	-	100	100	-
C14	126	LU	0	-	75	75	65
C14	126	RU	0	-	90	90	90
B811	100	LU	0	-	60	60	75
Total 15 cases Avg.106.4							

Continued (2)

FUSION METHOD - overlapping and ligating with chromic catgut

B631	83	RU	0	-	50	50	40
B631	83	RF	0	-	0	0	0
B634	58	RU	0	-	100	100	90
B634	58	RF	0	-	100	100	80
B653	36	RU	0	-	50	50	-
B810	315	LU	0	-	65	0	90
Total 6 cases	Avg. 105.5			Avg.	60.8 -	50. -	60.

NERVES CUT AND PERMITTED TO FALL BACK INTO SHEATH - NO ANASTOMOSIS

B383	203	RF	10mm	-	100	-	80
B383	203	RPT	10mm	-	100	-	75
B249	209	LF	10mm	.5mm	50	-	40
B248	83	LF	10mm	.5mm	100	-	-
B341	123	LF	10mm	.5mm	25	-	?
B331	187	RF	10mm	.5mm	100	-	40
B861	97	LU	15mm	.5mm	50	100	75
B861	97	LS	15mm	2.mm	50	50	50
B863	62	LU	15mm	1.mm	25	25	25
B863	62	LS	15mm	2.mm	50	50	40
B886	197	LS	20mm	2.mm	60	60	70
B911	335	LS	20mm	2.mm	25	25	100
B911	335	LU	10mm	1.mm	20	25	100
Total 13 cases	Avg. 161.1		14mm	1.1mm	58	47.8	63.2

Continued (3)

ANASTOMOSIS WITH SILK, WITH FASCIAL COVERING

B382	103	RPT	-	-	100	-	80
B383	203	LPT	-	-	100	-	70
B248	83	RPT	-	-	100	-	95
B341	123	RPT	-	-	100	-	50
B331	187	RPT	-	-	75	-	90
B400	74	LS	-	-	50	-	75
B401	71	LS	-	-	25	-	60
B402	73	LS	-	-	75	-	90
B408	276	LU	0	1mm	100	100	90
B379	252	LU	7mm	1mm	100	100	90
Total 10 cases Avg. 114.5				Avg.	82.5	100	79.

FASCIAL TUBULIZATION - Lewis & Kirk method

C343	24	LS	20mm	2mm	-	-	0
C343	24	LU	2mm	1mm	-	-	85
C344	23	LS	10mm	1.5mm	-	-	-
C344	23	LS	4mm	1mm	-	-	-
C341	21	LU	12mm	1mm	specimen not reported		
C342	42	LS	15mm	2mm	-	0	90
C342	42	LU	5mm	1mm	-	0	100
Total 6 cases Avg.	28.2		Avg. 9.7mm	Avg. 1.3mm		Avg.	91.6

Continued (4)

ANATOMOSIS WITH SILK AND ANIMAL MEMBRANE COVERING

B411	320	RU	3mm	-	100	100	100
B411	320	LU	12mm	-	55	85	80
B408	241	LS	60mm	1.5mm	0	0	60
B669	250	RU	10mm	1.5mm	75	75	25
B669	250	LU	12mm	1.5mm	75	75	80
B671	183	RU	10mm	1.5mm	25	25	25
B671	183	LU	10mm	1.5mm	20	20	-
B683	328	RU	10mm	1.5mm	85	85	100
B683	328	LU	5mm	1.5mm	100	100	-
B727	101	RU	15mm	1.5mm	75	75	90
B727	101	LU	10mm	1.5mm	75	75	90
B811	100	RU	12mm	1.5mm	100	100	95
B412	286	RU	10mm	2. mm	-	-	95
B412	286	LU	12mm	2. mm	-	-	90
B786	200	RU	0	-	-	-	80
B786	200	LU	0	-	-	-	90
B677	432	RU	10mm	2. mm	95	95	-
B677	432	LU	2mm	2. mm	90	90	-
Total 18 cases	Avg.252.3		Avg. 13.7mm	Avg. 1.4mm	Avg. 69.2	Avg. 71.4	Avg. 77.8

ANASTOMOSIS WITH SILK, COVERED WITH VEIN (Beckman)

B382	56	RU	-	-	50	-	90
B249	209	LPT	-	-	100	-	100
B249	168	RU	-	-	100	-	-
B248	83	LPT	-	-	100	-	85
B341	123	LPT	-	-	50	-	50
B331	187	LPT	-	-	100	-	85
Total 6 cases	Avg.137.6				Avg. 83.3		Avg. 82.

Continued (5)

VEIN TUBULIZATION - Corbett Method

C345	40	LS	15mm	1.5mm	?	0	0
C345	40	LU	4mm	1 mm	25	45	85
C351	40	LS	5mm	1.5mm	?	0	95
C351	40	LU	3mm	1 mm	?	0	100
C352	27	LS	10mm	1.5mm	-	-	-
C352	27	LU	2mm	1 mm	-	-	100
Total 6 cases	Avg. 32.6		Avg. 6.5mm	Avg. 1.2mm			Avg. 76.

ANASTOMOSIS WITH CHROMIC CATGUT

B599	168	LU	0	1 mm	0	-	-
B599	168	RU	0	1 mm	0	-	-

ANASTOMOSIS WITH SILK, COVERED WITH BONE TUBES

B382	56	LU	-	-	0	- stitches torn out
B341	90	RU	-	-	0	- " " "
B341	90	LU	-	-	0	- " " "

ANASTOMOSIS WITH SILK, COVERED WITH FIBER TUBE

B249	168	LU	-	-	0	stitches torn out

AUTOGENOUS TRANSPLANT

B669	214	LS	transplant 25mm	-	95	95	95
B671	97	LS	" "	-	75	75	25
C341	21	LS	" 35mm	-	-	-	10
Totals 3 cases	Avg. 110.6		Avg. 28mm	-	Avg. 85	Avg.85	Avg. 43

Continued (6)

NERVES CRUSHED WITH FORCEPS

B401	71	LF	-	-	25	-	50
B886	197	LU	-	-	100	100	100
C328	47	LS	-	-	85	85	85
C329	47	LS	-	-	?	25	95
C330	47	LS	-	-	?	80	-
Total 6 cases	Avg. 80.3				Avg. 70	Avg. 50	Avg. 82.5

NERVES LIGATED WITH CATGUT

B401	71	RF	-	-	25	-	20
C335	23	LS	-	-	?	-	60
C336	45	LU	-	-	?	20	100
C338	45	LS	-	-	?	25	100
Total 4 cases	Avg. 46.						Avg. 70.

NERVES LIGATED WITH SILK

C335	23	LU	-	-	?	0	-
C336	45	LS	-	-	?	0	90
C337	45	LS	-	-	?	0	100
Total 3 cases	Avg. 37.6						Avg. 95.

GENERAL SUMMARY OF EXPERIMENTAL RESULTS

TYPE OF OPERATION	Number of operations	Duration of Anastomosis (days)	DISTANCE BETWEEN ANASTOMOSED ENDS					Regeneration in reported cases	TYPE & DEGREE OF REGENERATION		
			Gap	Distance	Diameter	No Gap	Failures		Anatomical	Electrical	Histological
Plastic nerve flap	4	441	1	40mm	-	4	0	4	76	-	83
Fusion method overlapped & ligated with silk	15	106.4	0	0	.45mm	15	0	15	73.4	71.8	61.8
Fusion method overlapped & ligated with catgut	6	105.5	0	0	-	6	1	5	60.8	50.0	60.
Nerves cut and permitted to fall into sheath	13	161.1	13	14mm	1.1mm	0	0	13	58.	47.8	63.2
Anastomosis with silk with fascia covering	10	144.5	1	7mm	1. mm	-	0	10	82.5	100.	79.
Fascial tubulization (Lewis & Kirk)	6	23.2	7	9.7"	1.3mm	0	0	6	?	0	91.6
Anastomosis with silk and animal membrance covering	18	252.3	16	13.7"	1.4mm	2	0	18	69.2	71.4	77.8
Vein tubulization - Corbett method	6	35.6	6	6.5"	1.2mm	0	0	6	25.	11.2	76.
Anastomosis with silk, covered with vein(Beckman)	6	137.6	7	-	-	0	0	6	83.3	-	82.
Anastomosis with chromic catgut	2	168.	0	0	1.mm	2	2	0	0	-	-
Anastomosis with silk and no covering	7	260.	7	13. "	1 mm	0	0	7	85.7	90.	82.5
Anastomosis with silk covered with bone tube	3	78.6	3	-	-	0	3	0	0	-	-
Anastomosis with silk covered with fiber tube	1	168	1	-	-	0	1	0	0	-	-
Autogenous transplants	3	110.6	0	-	-	0	0	3	85.	85.	43.3
Nervescrushed with forceps	5	80.3	0	-	-	0	0	5	70.	50	82.5
Nerves ligated with catgut	4	46.	0	-	-	0	0	4	-	22.5	70.
Nerves ligated with silk	3	37.6	0	-	-	0	0	3	?	0	95.
Totals	112		62			29	7	105			
Averages		.150.5 (5mos)		15.mm	1.2mm				64.5	62.9	74.8
Per cent			55			25.8	6.6	93.4			

GENERAL SUMMARY OF OPERATIVE RESULTS

NERVES OPERATED ON	Number of operations	Average age	Males	Females	Single	Married	Average duration injury (months	CAUSE OF INJURY	Silk sutures	Chromic sutures	Fascial covering	Vein covering	No covering	Plastic flaps	Freed from adhesions	Gap	Distance	No gap
Facial	9	24	4	5	4	5	26	2 follow.mastoid op. 7 " trauma	6	0	-	4	2	2	1	0	0	9
Ulnar	7	20	6	1	7	0	6	2 asc.fracture elbow 5 " lacerated wounds	4	1	3	0	0	0	0	2	1"	-
Radial	1	24	1	0	1	0	2	1 lacerated wound	0	-	0	0	-	1	0	?	-	-
Median	7	23	7	0	6	1	18	7 lacerated wounds	3	3	5	-	2	1	0	2	1"	-
Musculo Spiral	10	36	10	0	3	7	28	9 asc.fract.humerus 1 lacerated wound	7	7	7	-	-	2	1	4	1½-1"	-
Ext.popliteal	4	30	4	0	2	2	12	1 asc.dislocat.fib. 3 lacerated wounds	3	0	3	-	-	1	0	2	(1)3" (2)¾"	-
Sciatic	2	22	2	0	2	0	(1) 96 (1) -	2 lacerated wounds	1	1	2	-	-	-	0	1	(1)¼"	-
Right recurrent larnygeal	1	39	1	0	0	1	12	1 foll.thyroidectomy	1	0	0	0	0	0	0	0	0	1
Totals	41		35	6	25	16			27	12	20	4	4	7	2	11		
Averages		28					15											
Per cent									65	29	49	10	10	19.5	5			

Note:- 19.5 per cent had plastic flap operations
80.5 per cent had end to end anastomosis

27 per cent had inter neural gaps
73 per cent had no gap or were not reported

GENERAL SUMMARY OF OPERATIVE RESULTS (continued)

NERVES OPERATED ON	Number of operations	Time improvement began (months)	Time maximum improvement (months)	TYPES OF IMPROVEMENT (%) Sensory	Motor	Trophic	RESULTS OF IMPROVEMENT IN PER CENT Improved	Indeterminate	Failures	Patients not heard from	Wound infections	Mortality	REMARKS
Facial	9	7.9	18.5	-	71	-	89	0	0	11	0	0	Longest injury 15yrs. Not heard from
Ulnar	7	10.	16.2	63	63	63	71	0	0	29	0	0	
Radial	1	-	-	-	-	-	-	-	-	100	0	0	
Median	7	10.9	21.	72	72	72	72	0	14	14	0	0	2 cases reported (jumped 1 inch
Musculo spiral	10	12.	27.	72	72	72	20	30	50	10	10	0	Long.gap 1½" not heard from
Ext.Popliteal	4	11.	24?	43	30	80	50	25	25	0	25	0	Longest gap became infect.
Sciatic	2	6.	18?	40	40	40	50	0	0	50	0	0	Case 8yrs.durat.part.improvm.
Right recurrent laryngeal	1	12.	36	-	90	90	100	0	0	0	0	0	
Averages		9.9	21.5										
Per cent				58	62	67	73.1	9.7	17.		4.8	0	Note :- Improvm.based on 41 cases.