

## ON THE RESULTS OF BRIDGING GAPS IN INJURED NERVE TRUNKS BY AUTOGENOUS FASCIAL TUBULIZATION AND AUTOGENOUS NERVE GRAFTS.

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It is now a surgical commonplace that the primary destructive effects of the missiles of modern warfare, the secondary slow destruction caused by prolonged suppuration, and the massive production of dense scar tissue, have together rendered the operative repair of injuries of peripheral nerve trunks an exceedingly difficult feat in many cases. Where end-to-end suture has been considered mechanically impossible, many alternative procedures have been recommended and practised during the past five years. At the present time all methods of bridging gaps in injured nerve trunks have fallen into disrepute, but it cannot yet be said that universal condemnation of such procedures is the rule. In particular, the use of autogenous, or even homogenous, nerve grafts is still considered by many to be a justifiable and satisfactory method of repair. In this paper is presented a study of the results of a series of operations in which autogenous nerve grafts combined with fascial tubulization, and tubulization alone, were used. In a total of 430 peripheral nerve operations performed in my services between March 1, 1915, and Oct. 31, 1919, 46 explorations revealed complete lesions in which end-to-end suture was considered at the time to be impossible of attainment. In 15 instances the gap in the injured nerve was bridged by a combination of an autogenous nerve graft and fascial tubulization, in 10 cases by fascial tubulization alone, and in 1 case by an autogenous vein graft: 26 operations in all.

TABLE OF NERVES IN WHICH THE BRIDGE OPERATIONS WERE EMPLOYED.

NERVE	FASCIAL TUBULIZATION AND NERVE GRAFT	FASCIAL TUBULIZATION ALONE	VEIN TUBULIZATION
Ulnar .. ..	6	4	—
Median .. ..	2	4	—
Musculospiral ..	3	1	1
Posterior interosseous	1	1	—
Sciatic .. ..	2	—	—
Posterior tibial ..	1	—	—
Totals .. ..	15	10	1

Total number of operations, 26.

It is interesting to note that 20 of these bridge operations were performed prior to December, 1917, out of a total of 106 nerve operations up to that date. These operations were based on the reputed value of both the nerve graft and fascial sheath at that period; and furthermore, in all my early operations a conservative attitude was deliberately adopted towards extensive freeing of nerve trunks, in view of the potential risks of endangering the vascular supply of the nerves explored. This high percentage of apparent failures to achieve end-to-end approximation is thus explained. The justification for the use of nerve grafts rested largely on isolated statements in the pre-war literature of peripheral nerve surgery, as it must be admitted that detailed and accurate end-results were not available. The use of fascial tubulization had a much more scientific basis, as seen

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by the results obtained in experimental nerve surgery in dogs by Dean, Lewis, and Kirk.<sup>1</sup> These observers, in a preliminary communication in 1915, and in a further elaborate study published in 1916, established beyond all doubt the occurrence of regeneration of axis cylinders across considerable gaps in nerve trunks in dogs; this regeneration proceeded in an orderly fashion from the proximal to the distal ends of the nerve trunks inside autogenous fascial tubes. In no experiment was collapse or obliteration of the lumen of the fascial tunnel noted. These results are undoubtedly suggestive of the possibility of similar phenomena occurring in human peripheral nerves.

In all my operations the fascial tube was regarded as the essential conducting tunnel, even when combined with a nerve graft, as it was illogical to suppose that a small cutaneous nerve could possibly conduct the axons of the total cross-section of the larger injured nerve.

**Operative Technique.**—The nerve grafts used were single segments of the radial, internal cutaneous, musculocutaneous, internal saphenous, and internal plantar nerves. The graft in every case was of considerably smaller calibre than the recipient nerve, and it was sutured to the cross-section of the proximal and distal ends with fine catgut. The whole area was surrounded by an autogenous fascial sheath, in most cases obtained from the fascia lata of the thigh. This tube, after closure, was distended with sterile olive oil, or its interior smeared with sterile vaseline. Where the nerve graft was omitted, the ends of the injured nerve trunk were connected inside the fascial tube by two fine catgut strands.

It has been possible to follow up 18 cases in which the above operations were performed, over varying periods of time. Furthermore, in four instances re-exploration of the nerve at a later date provided electrical, macroscopical, and histological information of considerable value. In the post-operative study of these cases, my colleague, Professor J. S. B. Stopford, has taken the major share. I am indebted to him for free access to his detailed records of all peripheral nerve injuries seen in my services, and for his collaboration, which has necessitated almost daily association during the past three years.

The histological investigations on the material provided by the secondary operations are at the present time incomplete, but will be made the subject of a future communication by Professor Stopford.

### REPORTS OF CASES.

#### *Group A.*—FASCIAL TUBULIZATION COMBINED WITH NERVE GRAFT.

##### *Case 1.*—Musculospiral nerve injury, complete, lower third of the left arm.

H. W. (civilian). Wounded Oct., 1916. Compound fracture left humerus; severe laceration of soft tissues in region of elbow; fractured radius and ulna; resulting bony ankylosis of elbow at right angles.

**OPERATION,** June 5, 1917.—Complete destruction of nerve trunk, with  $2\frac{1}{2}$ -in. gap; ankylosis of elbow prevented end-to-end approximation of the nerve; radial nerve graft and fascial sheath inserted.

**AFTER-TREATMENT.**—Regular; examined repeatedly. July 6, 1918.—No sign of motor or sensory recovery; no reaction to galvanism in any muscle of the extensor group. July 13, 1918.—Tendon transplantation performed. Feb. 13, 1919.—Function of the tendon transplantation is good; is now working. No alteration in the nerve syndrome. Aug. 6, 1919.—Functional capacity afforded by tendon transplantation is maintained. No change in the nerve syndrome.

**RESULT OF OPERATION.**—No sign of regeneration after twenty-six months.

##### *Case 2.*—Musculospiral nerve injury, complete, middle of upper arm.

Pensr. A. Wounded July 1, 1916. Compound fracture of humerus, extensive destruction of triceps muscle, and prolonged suppuration.

**OPERATION,** July 14, 1917.—The nerve trunk in the region of the lesion was represented by a fibrous cord 4 in. in length. Radial nerve graft and fascial sheath inserted.

**AFTER-TREATMENT.**—Regular; seen repeatedly for examination. Feb. 28, 1919.—No sign of regeneration, no galvanic response in extensors. Sept. 25, 1919.—No sign of regeneration. Condition as before. Oct. 4, 1919.—Tendon transplantation performed.

**RESULT OF OPERATION.**—No regeneration after twenty-six months.

**Case 3.—Complete median nerve injury, upper third upper arm.**

Pte. B. Wounded Aug. 4, 1916. Compound fracture of humerus ; gross atrophy of upper arm, fibrosis of the biceps.

OPERATION, June 12, 1917.—In the region of the scarring the median nerve was represented by a fibrous cord 3 in. in length. Internal cutaneous nerve graft and fascial sheath inserted.

AFTER-TREATMENT.—Regular ; examined repeatedly. Six months after the operation there was an apparent action in the flexor longus pollicis, but this was later proved to be a trick movement. Ten months after the operation an apparent diminution of the area of anaesthesia in the median area was noted. March 8, 1919.—No sign of motor recovery ; no galvanic response in any median muscles ; Tinel's sign absent. There is a palpable bulb on the nerve trunk proximal to the graft. The patient has developed a trick movement which closely simulates action in the palmaris longus. There is also apparent voluntary power in the flexor sublimis digitorum. Re-exploration advised.

RE-EXPLORATION MEDIAN NERVE, April 30, 1919.—Exsection of the grafted area, end-to-end suture. The median nerve trunk was found to terminate above in a large bulb which was adherent to the adjoining remains of the coracobrachialis muscle ; running down from the bulb was a narrow flattened cord, which was recognizable as composed of the original fascial sheath. When traced downwards this fine cord became continuous with the distal part of the nerve trunk, which was only half the calibre of the nerve trunk above the level of the graft. Faradic stimulation of the nerve trunk above and below the grafted area, and of the area itself, gave absolutely no response in any muscle in the forearm or hand. The grafted area was resected, the line of section passing above the proximal bulb and through the normal nerve trunk below. On the cross-sections the nerve bundles were seen to be of the gelatinous type. End-to-end suture was accomplished, with the elbow in acute flexion and the arm adducted to the side. May 9, 1919.—Motor and sensory phenomena precisely as before operation ; the trick movement in the palmaris longus and the apparent activity of the sublimis digitorum is still present.

RESULT OF NERVE-GRAFT OPERATION.—No sign of regeneration twenty-one months after operation.

**Case 4.—Ulnar nerve injury, left forearm.**

L.-Cpl. D. Wounded July 1, 1916.

OPERATION, Dec. 20, 1916.—Gap of 2½ in. revealed ; musculocutaneous nerve graft and fascial sheath inserted.

AFTER-TREATMENT.—Regular. Lost sight of patient for a considerable period. Feb. 13, 1919.—Full motor and sensory loss ; Tinel's sign absent.

RESULT OF OPERATION.—No sign of motor, sensory, or sympathetic recovery after twenty-six months.

**Case 5.—Musculospiral nerve injury (left).**

Pte. H. Wounded March 27, 1916. Compound fracture of the humerus, with necrosis ; prolonged suppuration ; extensive destruction of the triceps.

OPERATION, March 21, 1917.—The musculospiral nerve was completely obliterated over an extent of 5 in. Radial graft and fascial sheath inserted.

AFTER-TREATMENT.—Regular until February, 1918 ; examined repeatedly. Feb. 28, 1919.—Complete paralysis of the extensor group ; sensory loss as before operation ; Tinel's sign absent.

RESULT OF OPERATION.—No sign of regeneration, motor or sensory, after twenty-three months. Tendon transplantation advised, but refused.

**Case 6.—Ulnar nerve injury, left forearm.**

Pte. H. Wounded Sept. 9, 1916. Non-union of fracture of the ulna.

OPERATION, April 3, 1917.—Gap 2½ in. in nerve before trimming ; radial graft and fascial sheath inserted.

AFTER-TREATMENT.—Regular ; examined repeatedly. April 21, 1919.—Full motor and sensory loss ; vasomotor paralysis as before ; Tinel's sign absent.

RESULT OF OPERATION.—No sign of motor, sensory, or sympathetic recovery after two years. Re-exploration advised, but refused.

**Case 7.—Median nerve injury, right forearm.**

Pte. M. Wounded Sept. 26, 1916. Compound fracture of the radius, with non-union ; extensive muscle and tendon destruction, with matting and contractures.

OPERATION, May 30, 1917.—Six-inch gap in the trunk was revealed ; this was bridged by a musculocutaneous graft and a fascial sheath.

AFTER-TREATMENT.—Regular. Fourteen months after the operation there was an apparent action in the abductor pollicis. The thenar eminence showed practically no flattening ; no sensory recovery. Feb. 10, 1919.—Full median sensory loss, with vasomotor paralysis ; no Tinel's sign ; apparent action of all muscles in thenar group ; (? abnormal nerve supply). Sept. 5.—Condition as before.

RESULT OF OPERATION.—No true sign of regeneration, motor, sensory, or sympathetic, after twenty-six months. The ununited fracture of the radius has since been treated by bone-shortening of the ulna. Re-exploration of the grafted median nerve is contemplated.

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### *Case 8.—Ulnar nerve injury, right forearm.*

Pte. R. Wounded April 9, 1917. A complete lesion of the median nerve co-existed with extensive laceration of the bellies of the flexor muscles.

OPERATION, Aug. 29, 1917.—End-to-end suture of median nerve; ulnar nerve showed extensive destruction of the trunk;  $3\frac{1}{2}$ -in. gap; musculocutaneous graft and fascial sheath inserted.

AFTER-TREATMENT.—Regular; examined repeatedly. The median nerve showed steady signs of regeneration, and at the end of eighteen months there was recovery in the thenar muscles and slight residual analgesia. The ulnar nerve syndrome remained unchanged, and at the end of eighteen months there was a complete absence of any regenerative sign.

RE-EXPLORATION OF ULNAR NERVE.—The grafted area was excised, and end-to-end suture of the nerve performed after displacement in front of the internal epicondyle.

DESCRIPTION OF THE GRAFTED AREA.—This appears as a soft collapsible tube, the fascia being unchanged in physical appearance and presenting few adhesions to the surrounding tissues. The graft could not be felt inside the tube; on splitting the tube along the original line of its closure, it was found that the lumen was almost completely obliterated, and, to the naked eye, there was no sign of the nerve graft.

DESCRIPTION OF MICROSCOPICAL SECTION (Professor J. S. B. Stopford).—The proximal end shows a neuroma formation; in the centre of the fascia lata are seen a few bundles of wavy fibres occupying the position of the graft; no fibres seem to have reached the distal segment of the nerve.

RESULT OF OPERATION.—No sign of ulnar regeneration after eighteen months.

### *Case 9.—Ulnar nerve injury in the region of the left elbow.*

Cpl. D. Ankylosis of elbow-joint.

OPERATION, May 18, 1917.—Gap of  $2\frac{1}{2}$  in. revealed; end-to-end suture was prevented by the fixation of the elbow-joint. Internal cutaneous nerve graft inserted with fascial sheath.

AFTER-TREATMENT.—The patient had regular treatment at Shepherd's Bush Special Military Surgical Hospital, and was discharged at the end of twelve months with no sign of any recovery in the ulnar nerve.

RESULT OF OPERATION.—Complete absence of any signs of regeneration after twelve months.

### *Case 10.—Posterior interosseous nerve injury.*

Cpl. R. Wounded Sept., 1916. Bony ankylosis of elbow-joint.

OPERATION, March 17, 1917.—Gap of  $2\frac{1}{2}$  in. in the posterior interosseous nerve; radial nerve graft and fascial sheath inserted.

AFTER-TREATMENT.—Irregular. March 18, 1919.—No sign of recovery in any muscles of the extensor group. No response to faradism; profound wasting of the extensor bellies. Tendon transplantation advised; this operation was performed; functional result good.

RESULT OF OPERATION.—Complete absence of signs of regeneration after two years.

### *Case 11.—Sciatic nerve injury (left).*

Pte. C. Wounded Nov. 6, 1915. Compound fracture of femur; complete ankylosis of knee-joint; extensive destruction of posterior thigh muscles.

OPERATION, March 8, 1918.—Gap of 6 in. in the sciatic nerve; lesion quite irreparable. Insertion of internal saphenous nerve graft and fascial sheath. March 8, 1919.—Complete absence of any signs of regeneration.

RESULT OF OPERATION.—No signs of regeneration after one year.

## *Group B.—FASCIAL TUBULIZATION OPERATIONS.*

### *Case 12.—Musculospiral nerve injury.*

Pensr. B. Wounded Aug. 3, 1916. Compound fracture of the left humerus, with extensive destruction of muscles.

OPERATION, Nov. 3, 1917.—Destruction of musculospiral over a length of 5 in.; gap bridged by fascial sheath and catgut strands.

AFTER-TREATMENT.—Irregular; but seen repeatedly for examination.

RESULT OF OPERATION.—No sign of motor or sensory recovery after fourteen months. Extensor bellies practically disappeared. Tendon transplantation advised.

### *Case 13.—Ulnar nerve injury, right forearm.*

Bdr. D. Wounded April 15, 1917.

OPERATION, Nov. 16, 1917.—Gap of 3 in. found; fascial sheath and catgut strands inserted.

AFTER-TREATMENT.—Regular.

RESULT OF OPERATION.—No sign of motor, sensory, or sympathetic recovery after fourteen months.

### *Case 14.—Median nerve injury, right forearm.*

Pensr. H. Compound fracture of radius and ulna, with considerable destruction and matting of flexor bellies.

OPERATION, July 9, 1918.—After extensive freeing of the median nerve there was a 2-in. gap, even with the elbow in acute flexion. The gap was bridged by a fascial sheath and catgut strands as a temporary measure. March 14, 1919.—No sign of regeneration.

**OPERATION, March 28, 1919.**—Exsection of the bridged region, end-to-end suture. At the second operation the fascial sheath was found to be a collapsed tube showing complete obliteration of its lumen. The nerve trunk above the sheath was indurated, and presented a slight bulbous thickening; a corresponding appearance was seen at the distal extremity of the sheath. End-to-end suture was obtained, after extensive freeing of the nerve trunk, with the wrist and elbow acutely flexed.

**RESULT OF OPERATION.**—No sign of regeneration after eight months.

**Case 15.—Ulnar nerve injury, left forearm.**

**PENSR. B.** Compound fracture of the radius, July 13, 1916, with non-union.

**OPERATION, May 21, 1918.**—After exsection of  $2\frac{1}{2}$  in. of fibrosed nerve trunk, a gap of  $\frac{3}{4}$  in. was left. This was bridged by a fascial sheath and catgut strands as a temporary measure. March 1, 1919.—Tinel's sign absent; ? recession of analgesia; no motor recovery.

**RESULT OF OPERATION.**—No definite sign of regeneration after nine months. Re-exploration of the nerve was postponed owing to the patient's poor general health.

**Case 16.—Median nerve injury, right forearm.**

**PENSR. C.** Wounded July 11, 1915. Co-existing complete lesion of the ulnar nerve and matting of the flexor tendons and bellies; previous ligature of the brachial artery.

**OPERATION.**—July 21, 1918.—End-to-end suture of the ulnar nerve after anterior displacement. Median nerve, 3-in. gap bridged by sheath and catgut strands. No alteration in median syndrome after four months.

**RE-EXPLORATION OF MEDIAN NERVE, Dec. 13, 1918.**—The bridged area was exsected, and end-to-end suture obtained with ease. The segment removed consisted of a dense fibrous cord closely resembling a nerve trunk. The fat on the fascial sheath was still recognizable; no traces of catgut.

**HISTOLOGICAL EXAMINATION.**—Obliteration of the lumen of the fascial sheath, which is filled with young fibrous tissue, but in which there are no traces of any nerve fibres.

**RESULT OF OPERATION.**—No sign of regeneration after four months. Histological appearances of bridge suggest that no regeneration could have occurred even after a more prolonged period of waiting.

**Case 17.—Median and ulnar nerve injuries in region of right elbow.**

**Pte. D.** Ankylosis of the elbow in right-angle position; considerable destruction of the soft tissues.

**OPERATION, Sept. 4, 1917.**— $2\frac{1}{2}$  in. in both nerves bridged by fascial sheaths and catgut strands. Feb. 27, 1919.—No sign of any motor recovery; reaction of degeneration in muscles supplied by median and ulnar nerves; full sensory loss.

**RESULT OF OPERATION.**—No sign of regeneration after seventeen months.

**Class C.—AUTOGENOUS VEIN TUBULIZATION.**

**Case 18.—Musculospiral nerve injury.**

**Pte. H.** Wounded July 1, 1916. Compound fracture of the humerus, with extensive destruction of the triceps muscles.

**OPERATION, March 17, 1917.**—Musculospiral nerve was destroyed over a length of 6 in. Cephalic vein inserted into the gap as an autogenous tube. Feb. 27, 1919.—No sign of recovery.

**RESULT OF OPERATION.**—Failure of regeneration after twenty-three months.

**RESULTS OF OPERATIONS.**

Of the eighteen cases in the above series, in only three was the period of time after the operation under twelve months. Ten were examined eighteen months or more after the operation, and six of these after a two-year period. The result in every case was identical, viz., a complete absence of any clinical sign of recovery. This, in my opinion, is sound evidence in favour of regarding the operative procedures as permanent failures, but in itself is not enough. It may be suggested that the process of regeneration across gaps in nerve trunks, if physiologically possible, must be of necessity slow and, from the point of view of topography, inaccurate. Signs of recovery, therefore, would be long delayed. On the other hand, the re-exploration operations, particularly in two of the cases in which observations had been limited to a period of less than a year, have afforded evidence in favour of the permanency of the absence of regeneration. When a complete histological study of the tissues resected at secondary operations is available, I consider that further convincing evidence will be forthcoming as to the futility of the operations in question.

It will be noted that in two cases, Nos. 3 and 7, some months after the operation

there developed a change in the nerve syndrome. In *Case 3* the alterations were striking, and at first were regarded, after serious consideration, as indicative of regeneration. In this patient, after seven months there appeared an apparent action in the flexor longus pollicis; shortly after, the area of analgesia underwent an apparent diminution. Some time before the nerve was submitted to a secondary exploration there appeared what seemed to be a definite voluntary action in both the palmaris longus and flexor sublimis digitorum. With the possibility of 'trick' movements in mind, but with no definite proof of this, the median nerve was re-explored, and was found to be silent to direct faradic stimulation. Stimulation of the ulnar nerve in this region produced the movements investigated before the operation. In this patient there was an intractable contracture of the flexor bellies, and the activity of the flexor profundus digitorum produced in the relatively immobile fingers the movements characteristic of the sublimis muscle.

In *Case 7* the change in the syndrome was purely motor; after fourteen months the thenar eminence, previously flattened, showed a definite increase in volume, with an apparent recovery in the abductor pollicis muscle. In complete median nerve injuries one is accustomed to see excellent function and development in the flexor brevis pollicis belly so frequently, that one looks upon this muscle as supplied by the ulnar nerve in a large percentage of cases. In these cases, however, there is always a narrow zone of flattening along the radial border of the metacarpal in the position of the abductor. In the case under consideration this localized wasting of the abductor pollicis was conspicuously absent. Owing to the lack of any sensory change after twenty-six months, this apparent recovery in the abductor pollicis muscle is not considered indicative of true regeneration. At the time of writing, a secondary exploration of the nerve has not been carried out. Until this is done, the motor phenomena in this case cannot be explained with any certainty.

There can be little doubt that many so-called successful nerve-graft and fascial-bridge operations have been regarded as such owing to the development of signs of alteration in the motor syndrome, as manifested by muscle actions, which are purely trick movements. The path of the clinical observer in peripheral nerve injuries is beset with pitfalls. It is for this reason that the findings of exploratory operations, both primary and secondary, must be described with meticulous accuracy, particularly with regard to the results of direct faradic stimulation of the nerve trunks, motor branches, and muscle bellies exposed in the field of operation. The histology of any tissue resected completes an adequate conception of the morbid anatomy and physiology of an injured peripheral nerve.

### CONCLUSIONS.

1. In eighteen operations in which fascial tubulization combined with autogenous nerve grafts, fascial tubulization alone, and autogenous vein tubulization (one case), were used, there was a complete absence of any clinical sign of recovery. The shortest period over which observations were made was four months, the longest period twenty-six months.
2. Secondary exploration in four cases showed complete silence of the nerve trunk to direct faradic stimulation. End-to-end suture was accomplished in all after exsection of the bridged segment.
3. At the re-exploration operations, partial or complete obliteration of the lumen of the fascial tube was noted.
4. In two specimens examined histologically, one, a tubulization alone, showed obliteration of the lumen of the tube by fibrous tissue in which no nerve fibres could be found. In the second, a graft and tubulization combined, nerve fibres were present in the centre of the obliterated tubule eighteen months after the operation. There was no sign of continuity between the proximal and distal ends through this strand of nerve fibres.
5. The early re-exploration of all graft and fascial-bridge operations is advisable.

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### REFERENCE.

- <sup>1</sup> DEAN, LEWIS, and KIRK, *Jour. Amer. Med. Assoc.*, 1915, lxx; *Trans. Amer. Surg. Assoc.*, 1916, p. 486.