TENDON TRANSPLANTATION AND FIXATION FOR NERVE INJURIES.

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Wounds of nerve trunks, with the paralyses resulting therefrom, have been numerous during the campaign in East Africa, and the application of the right treatment for each case, has been one of the most interesting of the surgical problems submitted to us. The station in life of each patient, his chances of being able to continue treatment after leaving hospital, and his ability or otherwise, to get efficient apparatus have all been factors in deciding on the class of operation applicable.

In the operative treatment of nerves and paralysed muscles in this Force we have been guided by the work of Major-General Sir Robert Jones on poliomyelitis, and we have successfully applied his methods of tendon-transplantation and fixation in cases unsuitable for nerve suture, or in cases in which nerve suture had failed. Many such operations on paralysed and useless limbs have been carried out, and though none can be said to have actually failed, there is no doubt that our later cases have been more uniformly successful as regards end results. The production of these improved results has been attained by certain modifications in our original methods, and I will endeavour to describe those modifications in the text and to explain their rationale.

Tendon Transplantation.—This operation has been carried out in this Force for three types of nerve injury:

(a) Irreparable injury to the musculo-spiral nerve with wrist-drop.

(b) Similar injury to the median nerve.

(c) Injury to the musculo-cutaneous nerve in the leg with paralysis of the peronei muscles and resulting pes equino varus.

Before describing the operations carried out, and the modifications which we have found useful, let me state that in certain disabilities, due to severance of a nerve-trunk, and especially in the paralysis due to division of the musculo-spiral nerve, one is justified in recommending the operation of tendon transplantation in preference to that of secondary nerve suture. I think that this is probably the case even for British officers and men, while for the Indian and African soldier, and the porter, who want useful hands quickly, and who cannot, and in most cases certainly will not, carry out the long months of treatment essential for a successful result after nerve suture, I am certain that tendon transplantation is the operation of election. As regards usefulness to the Force, too, tendon transplantation is preferable, as it will return men with useful hands to the ranks in two or three months. Such a result is impossible after nerve suture.
In comparing the two operations for a case of drop-wrist, the proposition which the surgeon can lay before his patient is as follows: By nerve suture a perfect result is probable, but not certain; the result will be obtained after a year, or even two years, during which time the hand must be kept in continual extension, and electric treatment and massage must be energetically carried out. In the case of failure the operation of tendon transplantation is still available. By tendon transplantation a useful hand can be guaranteed after two or three months. It will not be a perfect hand, but it will do for holding and using a gun or rifle, digging, driving a motor car, and manual labour not involving fine movements of the fingers. I imagine that most men would choose the shorter time of waiting and the less perfect hand. A musician or a surgeon would consider the longer time not ill spent if he regained full use of his highly trained hand, but the majority of men would ask for quicker and more certain results.

That nerve suture, either primary or secondary, will certainly fail unless relaxation of the paralysed muscles is maintained, and may fail even with approved treatment, has been amply demonstrated to us by cases which have come into the base hospitals here for paralysis due to wounds in the early part of the campaign. The cases of two prisoners of war illustrate failure from lack of treatment after nerve suture. Both were wounded at the battle of Tanga in November, 1914; in both cases immediate suture of the musculo-spiral nerve was done by German surgeons, and from their account no further treatment of any sort was adopted. They were both taken prisoner some years later, and eventually reached the Prisoners of War Hospital at Dar-es-Salaam. Both these prisoners had typical dropped wrists and absolutely useless hands, and the scars of their wounds, and of the operations for suture of the trunk of the musculo-spiral were obvious in the upper arm. In one case a further operation of tendon transplantation had been attempted. The palmaris longus had been transplanted into the extensor tendons of the fingers, not of the thumb. This operation had absolutely failed to give any power of extension of the wrist—and, indeed, it could hardly be expected to do so. In both these cases the complete operation, as described below, was performed, and each man has now a useful hand, with power to extend and support the wrist, extension of the fingers and extension and abduction of the thumb.

Failure after primary nerve suture with continued treatment was illustrated by the case of a corporal of the Gold Coast Regiment, wounded some two years and a half before. Immediate suture of the divided musculo-spiral nerve was done, and extension and massage of the paralysed muscles carried out systematically. The extensors remained paralysed. The hand was useless. Tendon transplantation was carried out, and he left for West Africa, having rejoined his unit for duty.

The uselessness of the hand from dropped wrist is due to the inability to extend the hand and keep it extended to grasp an object, and to the
inability to extend the thumb and to abduct it from the fingers preliminary to grasping. If these two disabilities can be alleviated, a useful hand is obtained. A certain degree of finger extension by the lumbricales persists in every case of drop wrist, but unless the paralysed radial and ulnar wrist extensors, and the thumb extensors can be made good, no useful result can be expected.

To attain these objects the following transplantations have been carried out in cases of musculo-spiral paralysis:—

(a) The pronator radii teres, detached from its radial insertion, is transplanted into the long and short radial extensors.

(b) The flexor carpi radialis tendon, divided at the wrist, is brought round the radius, over the wrist extensors, and transplanted into the tendons of the extensores ossis metacarpi, primi and secundi internodii pollicis, and the extensor indicis.

(c) The flexor carpi ulnaris tendon, divided at the wrist, is brought round the ulna, and transplanted into the tendons of the extensor carpi ulnaris and the extensors of the three inner fingers.

The details of these procedures, as we have carried them out at the base hospitals here, are well shown in the accompanying illustrations.

The operation we now undertake is as follows: The arm is laid on its ulnar side on a small table placed at right angles to the operating table. An incision through skin and deep fascia, three inches long, is made over the middle third of the radius. The supinator longus and the two radial extensor tendons are recognized and separated, the former being retracted forwards. The radius is now exposed, and the tendon of the pronator radii teres recognized by the direction of its fibres. The thick tendon is well separated from surrounding structures by blunt dissection, a large hernia needle passed round it, and it is cut away from its insertion into the middle of the outer surface of the radius. In cutting the insertion free, the knife must be kept close to the bone, so that the tendon is cleanly separated. The muscle is then raised slightly from its bed to ensure that it is free. The wrist is then fully extended and held in that position by an assistant, and the extensor tendons having been pulled upwards, the tendon of the pronator teres (which should have a tail-like end if properly separated from the radius) is applied to the extensor carpi radialis brevis. At the most convenient point an incision is made through the short extensor tendon, and the pronator tendon passed through it. The pronator tendon now lies between the short and the long extensors, and is stitched in position by several fine silk sutures, some of which embrace all three tendons. All bleeding is stopped, the wound stitched, a temporary dressing applied, and the rest of the operation continued. The arm is turned on to its posterior surface. An incision of about one inch is made through skin and fascia over the tendon of the flexor carpi radialis at the wrist. The tendon is freed, an aneurysm needle passed under it, and it is pulled forward. By pulling on the tendon at the wrist, it can easily be traced in
its course up the arm, and a second short incision is made over it about
four inches above the former. The flexor carpi radialis tendon is again
recognized and freed through the upper incision. An aneurysm needle is
passed again round the tendon at the wrist, care is taken that the median
nerve is not included, and the tendon is divided as near to its insertion as
possible.

FIG. 1.—Tendon transplantation for drop-wrist on right side. The extensors of the thumb
and index finger demonstrated through a longitudinal incision on the posterior surface and
prepared for transplantation of the radial flexor tendon into them.

The arm is now turned on to its anterior surface, sterile swabs being
placed over the two small incisions. An incision three or four inches long,
is made from the wrist upwards, over the centre of the posterior surface of
the forearm. Through this incision the tendons of the extensor ossis
metacarpi pollicis, the extensor primi, the extensor secundii internodii
pollicis and the extensor indicis are recognized. When sufficiently
separated, a swab is placed over the wound, the arm is turned again on to
its posterior surface, the tendon of the flexor radialis found in the upper
wound and pulled out from its groove through the skin wound. From the
wound on the posterior surface, a long thin pair of forceps is passed under
the fascia and pushed out through the upper wound on the flexor surface.
The flexor tendon is seized by its end and drawn through to the extensor
surface in slanting fashion. Incisions are made in the four extensor
tendons previously recognized and the tendon of the flexor carpi radialis is
passed through them and stitched to each by very fine silk sutures.
The tendons of the extensor carpi ulnaris and the three inner extensors of the fingers are now recognized and freed. A swab is placed over the long wound on the extensor surface, and the arm once more turned with the flexor surface upwards. The flexor carpi ulnaris tendon is treated in the same way as the flexor carpi radialis; divided at the wrist, pulled out through a wound four inches above the wrist, and transferred to the extensor surface by being pulled under the fascia in slanting fashion round the ulna. The ulnar flexor tendon is then attached to the extensor carpi ulnaris and the extensors of the three inner fingers.

The five wounds are stitched, a dressing applied to them and to that over the pronator teres, and the hand is put up on a splint which maintains it in a position of extension.

![Image of tendon transplantation and fixation for nerve injuries](http://militaryhealth.bmj.com/content/35/2/124)
too, complained of persistent numbness at the base of the thumb and radial side of the hand. Perhaps we made our flaps too big, but we have had none of the oedema and no anaesthesia since we adopted the single longitudinal incision over the extensor tendons, described above, and the subfascial method of dealing with the flexor tendons. I think, therefore, that this modification is worthy of record and recommendation.

We were somewhat disappointed at first that our cases did not regain any useful degree of voluntary wrist extension. The hand could be raised, and held, in straight line with the forearm, but not beyond that. I think this was due to not completely freeing the pronator teres before its transplantation into the radial extensors, and to not including the ulnar extensor in the group into which the ulnar flexor was transplanted. Since adopting these modifications in our technique, the results, as regards wrist extension have improved. The extensors of the wrist work at a mechanical disadvantage as regards power; it is essential, therefore, that as much available power as possible should be transferred to them. I consider it highly important that the hand should be held in extension during these transplantations, and that it should be maintained in extension for a fortnight or three weeks after operation. After that, training in the use of the hand should begin. It is wonderful how soon the movements of extension of the thumb and fingers are learnt.

For irreparable injury to the median nerve the tendon transplantations advocated by Sir Robert Jones were carried out in one case, viz., the transplantation of the paralysed outer two tendons of the flexor profundus digitorum into the two inner tendons of the same muscle, supplied by the ulnar nerve. The flexor carpi ulnaris was made to take on the work of the flexor sublimis digitorum by the transplantation of all four tendons of the latter muscle into the tendon of the former. Finally the tendon of the extensor carpi radialis longior, divided near its insertion, was brought round the radius and inserted into the tendon of the flexor longus pollicis. This patient was transferred too early to give a definite statement as to the result.

For division of the musculo-cutaneous nerve in the leg, with paralysis of the peronei we have carried out transplantation of the tendon of the peroneus longus into the outer side of the active tibialis anticus. The tibialis anticus thus becomes a bifid tendon pulling up the outer and inner sides of the foot at the same time.

The initial stages of this operation are the same as those for fixation of the peroneus longus to the tibia described below. The tendon is recognized and divided in the leg about six inches above the outer malleolus. It is again found on the outer side of the foot well in front of the malleolus. An incision about three inches in length is now made through skin and fascia in the anterior mid line of the leg about four inches above the ankle. The thick tendon of the tibialis anticus is isolated. The peroneus longus tendon is pulled out through the incision on the outer side of the foot and
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transferred sub-fascially to the outer side of the tibialis anticus tendon, as shown in the illustration. The tibialis anticus tendon is tunnelled to receive the other, the foot is well extended, the peroneal tendon passed

Fig. 3.—The preliminary step in the operation of fixation of the peroneus longus tendon to the left tibia, or the transplantation of that tendon into the tibialis anticus. The two peroneal tendons are recognized below and in front of the external malleolus. The lower of the two is the peroneus longus.

The results of this operation have been excellent, the patient being able to bring the sole squarely to the ground, instead of walking on the outer edge of the leg.
foot. He has good power of extension at the ankle, though of course very little power of eversion. He can walk and run as well as ever, and will return as a useful soldier to the ranks.

The operation usually recommended for paralysis due to cutting of the musculo-cutaneous nerve in the leg is the transplantation of the insertion of the tibialis anticus from the inner to the outer side of the foot. I venture to recommend the modified operation I have described above as an improvement. I am not aware that it has been described or suggested before, and our experience is that by it the inversion of the foot is cured and the balance of the foot restored, without the disadvantage of weakening the inner arch of the foot by separation of the anterior tibial tendon from its normal insertion.

Tendon Fixation.—This operation has been performed many times in this Force, for various conditions, but it has been chiefly used for irreparable injury to the external popliteal nerve with consequent drop foot.

The technique we have employed has been that described by Sir Robert Jones, with trifling modifications. The stages of the operation are well shown in the photographs.

The details are as follows: The two peroneal tendons are isolated and recognized through a short incision below and in front of the external malleolus. The lower tendon is that of the peroneus longus. The peroneus longus tendon is again found and isolated through an incision about six inches above and slightly behind the external malleolus. The tendon is brought out through this upper incision and divided.

An incision three inches long is now made, four inches above the ankle along the anterior border of the tibia. The periosteum is divided within the limits of the incision and reflected from the internal and external surfaces of the bone. The tibialis anticus muscle and tendon is retracted to the inner side: With a burr a hole is drilled through the tibia large enough to admit the peroneal tendon.

A small incision is now made through skin and fascia just above the anterior annular ligament and just external to the tendon of the tibialis anticus.

We now turn again to the small incision on the external side of the foot. A broad hernia needle is passed round the long peroneal tendon and it is pulled down out of its groove completely outside the wound. From the small incision in front of the ankle a long pair of forceps is passed under the fascia and annular ligament to emerge at this small wound on the external side of the foot. The end of the tendon is grasped and drawn through. From the incision over the tibia the forceps is again pushed down under the fascia to emerge at the wound in front of the ankle. The end of the tendon is again grasped and drawn up into the wound over the tibia. The tendon is now passed through the hole in the tibia, the foot is pushed into an extended position, and the loop of the peroneus longus
drawn taut, and stitched firmly to itself and to the periosteum. The tibialis anticus tendon is divided, drawn firmly upwards and stitched over the loop and the upper end brought down and stitched over all.

![Image](http://militaryhealth.bmj.com/)

**Fig. 5.**—The long peroneal tendon is recognized and divided through an incision about six inches above the outer ankle, a hook passed round it at the ankle and traction applied.

![Image](http://militaryhealth.bmj.com/)

**Fig. 6.**—The peroneal tendon is drawn completely out through the wound below the external malleolus. A sinus forceps is passed under the fascia from above the anterior annular ligament. The end of the tendon is grasped and completely drawn through.

We find the slight modification of making a loop of the peroneus tendon an improvement on merely stitching it to the periosteum, or fixing it with a tack. By the loop method it can be drawn taut, and the resulting
The sinus forceps is again passed down from the wound over the tibia, and the peroneus longus tendon drawn up and passed through the tunnel in the tibia. In the figure it is held ready to be fixed by stitching to itself and the periosteum.

In paralysis of the peronei only, the peroneus longus tendon is transplanted into the unparalysed tibialis anticus. In the figure the peroneus longus tendon of the right side is passed through the anterior tibial tendon ready for stitching, after which the redundant piece seen in the forceps is cut away.
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anterior ligament is more likely to support the foot in the required position. It is, perhaps, worthy of note that we have found it advisable to make all the preparations for the reception of a tendon to be transplanted or fixed before that tendon is pulled out of its groove into the air. If left in its normal groove till the last moment it will not be injured during the preparation of its new position, and is less likely to form adhesions to surrounding structures along its new groove.

For irreparable complete division of the trunk of the sciatic nerve a series of operations have resulted in giving a dependable limb. The ankle is usually found to be fixed in a position of equinus, and the paralysed ham-strings contract, fixing the knee joint in semi-flexion. For such a case the following operations were carried out: (a) Lengthening of the tendo-achilles; (b) fixation of the peroneus longus and tibialis anticus as described above; (c) tenotomy of the ham-strings, and finally; (d) resection of the knee-joint to produce a stiff joint. The case I have in mind, a carrier, was many months in the jungle before he was found and passed through various field units to the base. It was then a matter for consultation as to whether amputation was not the only course remaining. I decided against it, and he has now a natural peg leg, which he will soon learn to use for carrying himself and perhaps a light load. I hardly think he would do so well on an artificial peg-leg, even if he could have got one, and of course a fixation apparatus for the knee-joint or ankle-joint was out of the question.

In paralysis due to injury of the ulnar nerve an attempt to unite the divided ends has been made in each case in the base hospitals here. This was done in view of the grave crippling produced by this injury, due to paralysis of the intrinsic muscles of the hand. No tendon transplantation will modify this, and the only hope is successful nerve suture. Luckily the ulnar nerve lends itself to such treatment very readily. It is easily accessible along its whole course, and by flexion of the wrist, straightening the elbow, or even altering the course of the nerve from behind to the front of the elbow, gaps of 1½ to 2 inches may be overcome and the nerve ends brought together. During the past six months I have carried out several secondary nerve sutures for the ulnar nerve, using subcutaneous fat to surround the ends after union and to prevent their adhesion to surrounding tissues. It is too early yet to report on the results of these operations, but I have hopes that they will all do well, as in each case I can trace the nerve in its new course, and there is no loss of continuity. In one case of an accident resulting in division of both ulnar and median nerves, primary suture was successfully carried out, and within a month the patient was able to tell which finger was lightly touched, with his eyes shut. He had no return of muscular power, but the abnormally rapid return of sensation justifies a hope that muscular power will be quickly restored.

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To Major-General Sir Robert Jones we are all indebted for the inspiration to attempt alleviation of these crippled limbs, and such success as we have attained is attributable to his work.