NEW USES OF TANTALUM IN NERVE SUTURE, CONTROL OF NEUROMA FORMATION, AND PREVENTION OF REGENERATION AFTER THORACIC SYMPATHECTOMY.

ILLUSTRATION OF TECHNICAL PROCEDURES*

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TANTALUM is a metal that causes practically no irritation on the part of human tissues. It has the added advantages of easy processing into plates, thin sheets, or wire at the factory, and of convenient sterilization, drilling, shaping, or cutting in the operating room. For use in operations on the nerves it is available in thin sheets (0.001 and 0.002"), in annealed rolls (approximately 0.00075") of convenient size for wrapping a nerve suture or an area of neurolysis, and in thinner foil (0.00025"). The latter has turned out to be too thin, having such a tendency to crumple and fragment that it has had to be discarded. For the past two years, before they were made available for commercial use, these products were extensively used and tested by the neurosurgical specialists in both the Army and Navy Medical Corps.

This paper presents adaptations of these new tantalum products which have proven to be of value in the operative treatment of severed peripheral nerves, painful neuromas, and in thoracic sympathectomy. These procedures can best be described by a series of simple sketches and reproductions of x-rays, with accompanying brief comments in the text.

NERVE SUTURE

Current statements to the contrary, even the finest silk sets up a definite amount of fibrosis when used as epineural sutures, and occasionally may produce a severe reaction. Under the most favourable circumstances a thin capsule of connective tissue is clearly visible to the naked eye around each silk knot, and in occasional instances the strands may be pushed apart by a dense mass of fibroblasts, as illustrated in Fig. 1.

Granted that the surgeon has good eyesight, 0.003" tantalum wire swedged onto fine atraumatic needles is the ideal material for suturing severed nerves. Finer than any other available stitch and also definitely less irritant to tissue, it is easy to tie and there is no tendency of the first half

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† These products can now be obtained for limited civilian use from the Ethicon Suture Laboratories of Johnson & Johnson at New Brunswick, N. J.
hitch of a square knot to slip. For this reason a slight but perceptible degree of trauma is avoided every time a suture is tied. The fact that this fine wire breaks when put under unnecessary tension is an added safeguard. A further unique advantage is tantalum’s relatively high opacity to x-rays, so that each delicate knot remains as a clear marker of the position and state of the line of anastomosis.

Colonel R. Glen Spurling, formerly in charge of neurosurgery at the Walter Reed General Hospital in Washington, and Lt. Colonel Barnes

Woodhall, his successor, first experimented with covering the line of a nerve suture with tantalum foil 0.00025" in thickness. It was soon discovered that foil tended to break up because of its extreme thinness and it was therefore discarded, although the early results were promising. Woodhall and other neurosurgical specialists in both the Army and Navy then utilized annealed sleeves of sheet tantalum 0.00075" in thickness, which were prepared for us by Professor Paul Weiss of the University of Chicago. Still more recently these annealed rolls of sheet tantalum have come into commercial production. Under proper circumstances, this method of protecting the area of nerve
anastomosis appears to be of definite value. This type of suture has now been used in 22 cases at the U. S. Naval Hospital at Chelsea over the past eighteen months, and this experience has led to several minor improvements in technique, which are illustrated in Fig. 2.

In this figure the annealed roll of tantalum (0.00075" thick) has been slipped over the proximal or distal stump before the nerve is sutured. On completing the suture it is drawn over the area of anastomosis. It can equally well be unrolled and slipped as a sheet beneath the completed line of suture. On release it recoils into its previous cylindrical form and can then be gently snugged up against the nerve trunk by one or more circular ties. These should be of 00 plain catgut and must never be tied tightly. At first silk or tantalum ties were used by a number of surgeons, with resultant impaired rate of regeneration. Re-exploration showed that the central stump of the nerve had swollen slightly and was constricted by the encircling metallic cuff. This has occurred twice in my own experience, but never since fine, rapidly absorbable catgut has been used.
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Fig. 2 (1) shows marker sutures of fine tantalum tied in a loose single knot through the epineurium just beyond each end of the tantalum sleeve. With this recent modification an x-ray can always establish the exact position of

FIG. 3. Position of metallic sutures indicates that nerve ends remain in good approximation. The photograph of this x-ray has been slightly retouched in order to pick out the metallic sutures, as these are too fine to reproduce well.

FIG. 4. Evidence of separation of sutured ends of nerve. At operation tantalum sutures were placed similar to those illustrated in Fig. 3. The gap between the nerve ends is shown not only by the shift of the actual epineurial stitches within the sleeve but also by the marker sutures. Note the extensive shift of the marker suture on the right. In spite of the fact that separation of approximately 1 cm. is shown, the nerve ends remained within the sleeve and very satisfactory regeneration has taken place across the gap. The photograph of this x-ray film has been slightly retouched in order to make the fine metallic sutures visible.

the anastomosed nerve ends. At first glance these extra marker sutures may seem unnecessary, because a displacement of the metallic strands at the suture line should show its separation. It is quite possible, however, for all the torn out sutures to remain attached to one end of the nerve and thereby
fail to demonstrate its separation. The roentgenogram reproduced in Fig. 3 was taken immediately after operation to ascertain the condition of a suture in the ulnar nerve. In this instance the ends of the nerve had been sutured with moderate tension under local anaesthesia. As the anaesthesia had worn off prior to closure of the incision, the patient was lightly anaesthetized with sodium pentothal. In the course of the application of a plaster bandage in flexion, the patient forcibly extended his wrist. All fears that the sutured nerve ends could have been pulled apart were dispelled upon viewing the film. In contrast, Fig. 4 shows distinct evidence of separation of a sutured posterior tibial nerve, which followed the development of a large pulsating false aneurysm from an undiscovered laceration in the side of the peroneal artery.

Another helpful use of tantalum in nerve repair is for marker sutures whenever the site of injury may need to be re-explored, as in securing severed nerve ends exposed in a fresh wound at the time of primary debride-

![Figure 5](image)

Fig. 5. Application of tantalum cap to stump of nerve for prevention of neuroma formation. (1) and (2) Resection of painful end-bulb neuroma. (3) The amputated end of the nerve is transfixed by a fine silk stitch and covered by a sleeve of tantalum. (4) The open end of the sleeve is crushed in a hemostat. (5) and (6) The flattened end is turned back on itself and crushed again, thereby fixing it firmly to the end of the nerve.
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PREVENTION OF REFORMATION OF EXCISED NEUROMATA

Although Boldrey’s¹ suggestion of drawing the nerve from which a painful neuroma has been removed through a tunnel drilled in a neighboring bone has been a partial answer to the problem of preventing their recurrence, there are many occasions when this procedure requires a considerable enlargement of the incision and unnecessary operative trauma. A simple snugly-fitting cap of sheet tantalum appears to answer the purpose equally well and requires no larger exposure than is necessary for the excision of the

neuroma. This convenient device was developed by Colonel Spurling at the Walter Reed General Hospital, where it has since been found effective by Lt. Colonel Woodhall, as it has been also at the U. S. Naval Hospital in Chelsea. The technical steps of its application are illustrated in Fig. 5 and an x-ray of such a cap in position is reproduced in Fig. 6. Relief of local hyperesthesia and tenderness at the nerve ending has given clinical evidence of success on numerous occasions, while direct inspection after reopening the incision has been carried out by Lt. Colonel Woodhall⁴ and by us, demonstrating effective prevention of end-bulb reformation. It is important not to
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apply such a tantalum cap when the nerve end lies so close to the skin that
the patient may notice a subcutaneous mass. In this situation, which is the
case in painful neuromata of digital nerves, Boldrey's procedure is preferable.

PREVENTION OF REGENERATION OF CENTRAL CONNECTIONS
OF DECENTRALIZED UPPER THORACIC GANGLIA IN
PREGANGLIONIC SYMPATHECTOMY OF
UPPER EXTREMITY

When this operation through a posterior third rib approach was described
by Smithwick, he recommended covering the second and third thoracic

sympathetic ganglia with a closed sleeve of fine silk gauze. The purpose of
this manoeuvre was to prevent regeneration, which frequently occurred even
when these ganglia were transplanted out of their normal bed and sutured
to the second intercostal muscle. Regenerating fibres from the fourth thoracic
ganglion or from the central stumps of the second and third intercostal
nerves were apparently able to bridge this gap. The substitution of a tan-
talum sleeve, closing its lower end by crushing in a haemostat (Fig. 7), has
simplified this step and should prevent the regrowth of preganglionic vaso-
constrictor fibres even more effectively. On theoretical grounds, there should
be less fibrosis and destruction of the two ganglia that are enclosed within
the sleeve. These structures contain an appreciable number of postganglionic
neurone cells, and it is therefore highly desirable that they should not degen-

Fig. 7. Application of tantalum cap to decentralized upper thoracic sympathetic ganglia to prevent re-connection with regenerating preganglionic fibres. (1) After the sympathetic chain has been divided below the third thoracic ganglion and its central connections with the second and third thoracic anterior roots have been divided, the tantalum sleeve is slipped over the mobilized cephalic stump. (2) The open end of the sleeve is crushed and then (3) bent back on itself and crushed again. (Compare with Fig. 71, p. 408, White, J. C., and Smithwick, R. H., The autonomic nervous system. New York: The Macmillan Co., 1941, 2nd ed.)
erate and thereby sensitize the denervated brachial arterioles to circulating adrenaline and sympathin.¹³

**DISCUSSION**

Time alone can tell whether the application of metallic tantalum sleeves with closed ends can prevent reformation of neuromata or the regrowth of preganglionic connections with decentralized upper thoracic sympathetic ganglia. These procedures are being reported at this early date because of their technical simplicity and early promising results in the treatment of two common complications of peripheral nerve wounds—painful neuromata and vasomotor disturbances. It is desirable that these methods be given a wide trial and their value assessed by a number of independent observers.

The technical advantages of suturing severed nerves with tantalum wire rather than silk, and particularly the advisability of protecting the suture line with a tantalum sleeve have been questioned. In our opinion, the use of tantalum sutures has come to stay for the following reasons:

1. Tantalum causes less tissue reaction than silk.
2. Metallic sutures are safer to use than silk in the presence of potential infection. This is of particular importance in view of the recent trend to early reparative operations reported by Churchill.² An increasing number of gunshot injuries of nerves are being sutured or loosely approximated overseas under the protection of penicillin within a short interval of the time of wounding.
3. Metallic suture material permits subsequent verification by x-ray that the approximated nerve ends remain in apposition.

The value of covering the area of nerve suture with a tantalum sleeve is less obvious, and proof that it results in better recovery of nerve function is still far from certain. No doubt better substitutes will become available, such as elastic films of collagen, which are just coming to clinical trial and which are gradually absorbed, but at present it appears that much may be gained by the use of tantalum sleeves under certain conditions encountered in the suture of peripheral nerves. The following points deserve comment:

1. Since a tantalum sleeve protects against ingrowth of scar tissue, less accurate approximation of the epineurium is necessary and fewer stitches are necessary to perform an anastomosis. Each additional suture injures a number of axis cylinders and leads to increased fibrosis at the line of anastomosis.
2. In a patient where the postoperative x-ray demonstrated a separation of the sutured nerve ends of the posterior tibial nerve over a centimeter in extent (Fig. 4), re-exploration on the thirty-fifth day demonstrated perfect gross reconstruction of the nerve within the sleeve of tantalum, and there has since been such perfect regeneration that this sailor has been able to return to active duty within six and a half months. This possibility has been suggested in the animal experiments reported by Weiss.¹¹ According to this same investigator, it also seems probable that the presence of a sleeve serves
to orient the down-growth of axones so that they cross the line of suture with minimal distortion.

3. Subsequent re-exploration with removal of the tantalum sleeve has invariably revealed a smooth, glistening reconstruction of the epineurium so that the exact point of suture has been hard to identify. This area is well supplied with blood vessels which run down from the proximal stump. The freedom from adhesions to surrounding tissues, when compared with nerves sutured without such protection, is striking. This is particularly true when the area of suture cannot be buried in a bed of muscle, but is exposed to the friction of adjacent tendons at the wrist, or contiguous bone where the peroneal nerve crosses the neck of the fibula, or where the radial nerve winds around the humerus.

One possible objection that has been raised to protecting an area of nerve anastomosis with any type of sleeve is the possibility that this portion of the trunk may be deprived of its blood supply. Tarlov and Epstein\(^6\) have pointed out that, in addition to the longitudinal supply of blood vessels along a nerve trunk, there are frequent vascular twigs which join it from neighboring vessels. In a simple anastomosis cutting these off over a length of several centimeters cannot make the slightest difference, as the longitudinal circulation within the nerve is more than adequate to supply its ends. In the course of nerve grafting, however, any factor that reduce re-vascularization from the surrounding tissues may well impair the viability of the grafted segment. Here it would be highly probable that the ingrowth of vessels from the proximal and distal ends of the nerve would be too slow to prevent necrosis of the graft and its turning into a barrier of scar tissue. Davis\(^6\) has very properly pointed out that “delaying the blood supply, even to a fresh graft, by surrounding the suture lines or the entire graft with metallic sheaths or tubes of any kind will only enhance the necrosis.” The use of sleeves of any type in nerve grafting is therefore not advisable.

Another theoretical drawback to any metallic suture or wrapping is the possibility of dangerous heating if these areas are subsequently exposed to high frequency induced currents, such as are developed by some of the modern diathermy machines used in physiotherapy. This danger is, of course, no greater than that encountered after the use of other varieties of metal which are so commonly used by orthopaedic, plastic, and dental surgeons. The probability of injury from induced high temperature appears to be remote, otherwise frequent accidents should have already been reported. Pudenz has tested the effects of short-wave diathermy on tantalum and other metals in the tissues of experimental animals. In a preliminary investigation\(^6\,^a\) he was unable to demonstrate any significant heating of the metal or evidence of thermal injury in the histological sections. In a more recent statement\(^6\,^b\) he has reaffirmed his belief “that short-wave diathermy in therapeutic dosage will not heat metals to a degree that would be destructive to contiguous tissues.” Nevertheless, experienced physiotherapists have always tried to avoid the risk of excessive heating induced by high frequency currents in
areas of the body containing metal. We therefore still feel that it is advisable to warn patients of this potential danger.

With these points in mind, it has become our practice to cover the area of nerve suture with a protective sleeve of fine sheet tantalum 1 to 2 cm. in length whenever it is impossible to bury the sutured nerve in a bed of uninjured muscle. This has now been carried out in a series of 22 cases. Such use of protective metal sleeves is not a fool-proof procedure, and requires certain very definite precautions. While sleeves of annealed tantalum 0.00075" in thickness are not subject to crumpling and fragmentation, as was the case with the thinner foil that was first used, they cannot be employed at a point of extreme flexion, such as where the median and ulnar nerves pass beneath the flexion crease at the wrist. Furthermore, they should not generally be employed unless the patient can be kept under continued observation by the surgeon who performed the operation and later progress observed. If the nerve fails to show clear-cut signs of regeneration in the minimal period to be expected, the area of suture is re-explored under local anaesthesia, the metal sleeve removed, and the sutured nerve tested by electrical stimulation for sensory and motor transmission. This has been carried out in only 7 of our 22 patients, all of whom have shown afferent transmission across the suture line and subsequent satisfactory recovery. There is one patient, however, in whom the application of the metallic sleeve may have been the cause of failure of regeneration of an ulnar nerve sutured at the wrist eight months ago. At two and one-half months after operation, when the patient was last seen prior to his transfer to another Naval Hospital, he had recovered sensation to pin-prick 2 cm. down his hypothenar eminence. As a result of his transfer he was not followed with sufficient care to make sure of a satisfactory recovery, and he was discharged from the service by Medical Survey at too early a date. In answer to a recent follow-up letter he has reported that he has had no further recovery. This single failure of a nerve to regenerate after an apparently satisfactory sleeve suture serves to emphasize the importance of keeping every case under personal observation until there has been a good recovery of function. Otherwise the use of these sleeves is not justified. In all the other cases, in which there has been an adequate period of observation, it has been our impression that these men have done as well as, or better than, those with simple suture in whom no sleeves were used. The following examples are quoted to bring out this point:

Kenneth C., Pfc. USMC. Five months prior to suture this Marine had been struck by the empty metallic jacket of a Japanese .25-caliber bullet, which penetrated his forearm butt end first just below his elbow. The median nerve was completely divided and the surrounding flexor muscles of the forearm were severely traumatized by the disruptive effect of the defective bullet. On account of the excessive fibrosis the line of suture was protected by a sleeve of tantalum, which was removed nine weeks later. When discharged from the Marine Corps after eight and one-half months, anaesthesia of the palm and fingers had entirely disappeared. Although the tips of the first three fingers were still hypaesthetic, a trophic ulcer of the index finger tip had healed. There was good recovery of the flexor sublimis and opponens pollicis, with definite evidence of early reinnervation of the flexor pollicis longus and flexor profundus
muscles. Electrical skin resistance determinations showed that sympathetic axones had regenerated to the proximal phalanges.

George B., Lt. (jg), MC, USNR. This young medical officer had suffered a severe laceration over the anteromedial aspect of his wrist two months before. The lacerated tendons and ulnar artery had been dealt with satisfactorily at the primary debridement. After excision of a long fusiform neuroma and the contiguous fibroed areas of the ulnar nerve, it was necessary to transplant its trunk in front of the elbow and free up its entire length in the forearm, in order to permit a suture without tension. The suture line was protected with a tantalum sleeve because it lay in contact with the tendons and considerable scar tissue. Sensory recovery was rapid and the patient could feel a pin-prick over the entire ulnar area within a period of five months. Now at eleven months there has been good recovery of light touch and vibratory sense. The points of two pins can be differentiated at 3 cm. on the palm and 2 cm. on the little finger. There is no visible atrophy of the hand, but this was less pronounced than usual at the beginning. He has strong adduction of his thumb, good interosseus power in the index and ring fingers, and some adduction of the little finger. Electrical skin resistance tests show practically complete recovery of the sympathetic axones. He has recently assisted us in performing other nerve sutures and has an excellent surgical hand.

Parker J., GM 3/c, USN. A month prior to the suture of his common peroneal nerve this sailor had been struck by a shell fragment over the head of his fibula, which had not completely severed the nerve but left it reduced to a narrow band of scar tissue 1.5 cm. in length. This area was excised, the freshened ends of nerve sutured with tantalum wire, and covered with a tantalum sleeve where the completed suture lay in contact with the neck of the fibula. The speed of sensory recovery down this man's leg is difficult to explain. At two months only two small islands of hypesthesia, approximately 2 by 6 cm. in extent, remained just above the ankle and on the dorsum of his foot above the big toe. When last seen at three and one-half months only faint patches of hypesthesia could be detected over these areas, and light touch was well perceived throughout. Two-point discrimination was normal above the ankle, and on the dorsum of the foot only twice that found in corresponding areas on the opposite side. Although the anterior tibial group of muscles had not yet recovered, there was fair power in the peronei, and electrical skin resistance determinations showed that sympathetic recovery was already complete.

SUMMARY

1. The use of fine wire and sheets of metallic tantalum are discussed in connection with both the repair and the prevention of regeneration of nerves. This element causes practically no reaction on the part of neighboring tissue cells, and it is now available in several forms of especial value in operations on peripheral nerves.

2. It is ideal for nerve suture, as it can be drawn to extreme thinness (0.003") ties with ease, and can also be subsequently visualized in the x-ray as a marker of the position of the divided nerve ends.

3. In sheets 0.001" thick it can be cut and rolled to fit the end of a nerve stump from which a painful neuroma has been removed. By crushing the distal open end a snugly fitting cap is formed which effectively prevents reformation of the neuroma.

4. The same procedure is recommended for sealing off the cephalic stump of the divided thoracic ganglioneuronal chain in preganglionic sympathetic denervation of the upper extremity.

5. Annealed rolls of sheet tantalum (0.00075") constitute a distinct improvement over the former use of foil in the protection of nerve anastomoses.
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Unlike the finer foil, these sheets show no tendency to crumple or fragment, and their use is of real value under special circumstances which are often encountered in wartime injuries. Certain precautions are listed which are of great importance in their application.

The authors are indebted to Professor Paul Weiss of the University of Chicago for preparing the original supply of annealed sleeves of sheet tantalum, and to Dr. I. R. McCall of the Ethicon Suture Laboratories for generously furnishing a supply of all the above-mentioned tantalum products before they came into commercial production.

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