A METHOD OF FLEXOR TENDON SUTURE

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The results of flexor tendon repair in the middle zone or Bunnell's "no-man's land" are frequently poor. Direct tendon suture or excision of the damaged tendon and replacement with a free tendon graft give variable and uncertain results. Failure is largely due to adhesion formation between the tendon and surrounding tissues which limits the normal gliding action of the tendon.

MECHANISM OF TENDON HEALING

The work of Potenza (1962), and later work from Birdsell, Tustanoff and Lindsay (1966) and Dodd, Sigel and Dunn (1966) using radioisotopes, have shown that only sheath tissues provide active healing elements. The tendon is united by fibroblasts produced from the sheath which invade the injured area. Collagen is laid down initially in an irregular pattern and later is reorientated along the line of the tendon (Peacock 1964).

Nutrition is provided by adhesions which ideally are filmy and do not interfere with function. Adhesions are thus to some degree essential, as has been shown by the failure of tendons to unite within tubes that completely separate the tendon from the surrounding tissues (Potenza 1963).

![Figure 1: The barbed tendon suture.](image)

It has been shown that raising a skin flap, excision of the sheath, and even excision of the sublimis, give rise to little adhesion formation, but damage to the tendon produces adhesions at the site of damage. Even pricking produces adhesions at the site of injury. Instrumental crushing trauma of the tendon is particularly prone to produce adhesions (Lindsay and Thomson 1960). Lindsay, Thomson and Walker (1960) showed that gap formation is a major cause of poor clinical results from direct tendon repair and is associated with increased adhesion formation.

The usual methods of tendon suture produce additional adhesions, firstly because there is inevitable trauma to the external surface of the tendon as the suture is inserted, and secondly because a gap will form if firm apposition of the tendon ends is not maintained.

A more effective type of tendon suture should have the following attributes. 1) It should not produce any additional trauma to the tendon. It has already been shown by Verdan (1960) and by McCash (1961) that when special care and atraumatic techniques are used the results
of primary suture in the mid-zone can equal those of tendon grafting. 2) It should provide an increased grip which prevents or reduces gap formation and allows earlier mobilisation after suture.

The period of immobilisation, however, must not be too short. Increased activity during the early phase after suture gives an increased inflammatory reaction and succeeding fibrosis. In addition, the softening of a tendon, which is greatest at the fifth day after injury (Mason and Allen 1941), will reduce the grip of any suture on the tendon.

THE BARBED WIRE SUTURE

The suture which has been finally devised and modified consists of a length of seven strands of wire (44 standard wire gauge) 20 centimetres long. At each end is mounted a straight cutting needle 30 millimetres long (Fig. 1). On the centre of the wires are mounted two sets of four barbs facing in opposite directions, each set being spread over a distance of 25 millimetres with a 3 millimetres gap between the two sets. The barbs have a maximum span of 1.3 millimetres and are mounted in a plane at 45 degrees to each other. The barbs must also be at an angle of 30 to 45 degrees to the line of the wire to obtain maximum grip. Human profundus tendon in the adult has the minimal dimensions of 3 millimetres by 5 millimetres.
Since this paper was completed a similar principle has been reported independently by McKenzie (1967) using a barbed nylon suture. The barbs were much finer and more numerous. No cases of its use in man are reported.

Method of insertion—The divided tendon must be exposed over a distance of 7 centimetres. One end of the divided tendon is gripped in a special clamp (Fig. 2), holding as small a length of the end of the tendon as will allow an adequate grip. The needle is then passed through the hole in the centre of the clamp up the tendon until the complete length of the needle has been inserted. No difficulty is encountered in the manoeuvre (Fig. 3). The point of the needle can then be made to emerge on the surface of the tendon by kinking the tendon near the needle tip. It should be confirmed at this stage that the point of exit of the needle is at least 2·5 centimetres away from the site of tendon division. The needle, wire and finally the barbs can be drawn through the holder. The barbs are thus embedded in one end of the tendon. If for reasons of exposure the needles cannot be made to emerge far enough up the tendon, there may only be room for three barbs within the tendon. One barb must be brought through the same exit point as the needle. This slightly increases the trauma at the site and is not ideal. The small section of tendon held in the clamp is then resected with a knife, leaving a flat surface (Fig. 4).

The procedure is repeated with the other needle and barbs into the other tendon end. This opposes the two tendon surfaces. If the contact is not considered to be complete, it can be increased by holding one tendon end in a damp swab and putting traction on the wire at this end. When it is certain that the situation is satisfactory, both wires are cut off flush with the tendon surface.

No case of the point of a barb projecting outside the tendon has occurred.

EXPERIMENTAL EVIDENCE

The suture was used in two groups of experiments, firstly on cadaveric human profundus tendon, and secondly in a series of operations on dogs.

CADAVERIC HUMAN TENDON

The suture was inserted into a length of fresh human profundus tendon from a cadaver. Increasing traction was applied to the tendon-suture junction with a spring balance device (Fig. 5). A steel marker suture was placed in the tendon, and radiographs were taken as increasing weights were applied. This allowed accurate measurement of the amount of movement of the barbs within the tendon.

Results—The results with four barbs inserted are shown in Figure 6. The barbs moved the following distances within the tendon: at 500 grams, 0·5 millimetres; at 1 kilogram, 1 millimetre; at 1·5 kilograms, 2 millimetres; at 2 kilograms, 2 millimetres; at 2·5 kilograms, 3 millimetres; at 3 kilograms, 3·5 millimetres. The wire broke at 3·1 kilograms.

If two barbs only were inserted they tore out at from 1·8 to 2 kilograms, the amount of slipping in a typical experiment being: 0·5 kilograms, 1·5 millimetres; 1 kilogram, 2·5 millimetres; 1·5 kilograms, 4·5 millimetres. Thus two barbs do not obtain nearly such a firm grip on the tendon. Prolonged traction, for example 1·2 kilograms for six hours with four barbs, did not produce any significant shift.
In order to correlate these figures with other relevant facts the following observations are recorded. 1) "Pulvertaft" sutures of two strands of 40 SWG wire snapped at 2·1 kilograms when inserted into human tendon. 2) A human sublimis tendon in a normal adult can exert a tension of from one to two kilograms at maximum effort. This tendon was tested because it could be isolated in its action from the profundus tendon, and its power measured on the spring balance device. 3) The tone in a resting finger flexor tendon is from 80 to 160 grams (Omer and Vogel 1965). 4) An attempt was also made to measure the tension in the flexor sublimis tendon of a dog, as this was relevant to the second group of experiments to be described. The flexor sublimis tendon was exposed in a dog weighing 9 kilograms as described later. A strain gauge of the same width as the tendon was sutured into place with wire sutures after resection of a length of tendon equal to the length of the strain gauge (Fig. 7). The sublimis muscle was then stimulated electrically, and changes in tension on the strain gauge were recorded. On the following day further records were made with the dog standing and walking. The values obtained were as follows: electrically stimulated muscle 300 grams, dog standing 600 grams, dog walking 1,000 grams. It was noted that the dog when walking, although not in pain, was not putting its full weight on this leg, so these values are probably somewhat lower than those for a normal dog.

Conclusions—This barbed suture obtains a grip on the tendon beyond the breaking strain of standard tendon suture wire, well beyond the tone in flexor tendons and in movements of the finger not against resistance. Three or four barbs obtain an adequate grip on the tendon, but if only two barbs are inserted the efficiency of the grip is reduced.

Flexor Sublimis Tendon of a Dog

Anatomy—The flexor sublimis tendon of the dog at the level of the radiocarpal joint is a single tendon, of similar size to the human profundus tendon in the fingers. Proximally it merges into its muscle belly and distally it divides into slips to the digits of the foot. There
is a length of 6 centimetres of tendon suitable for the experimental insertion of the barbed suture. There is no fibrous sheath.

Operative technique—Medium sized dogs weighing about 9 kilograms were anaesthetised with intravenous Pentothal followed by halothane and oxygen administered by an endotracheal tube. Both forelegs were shaved, cleaned with iodine, and draped with sterile towels. The incision was centred on the radiocarpal joint, running medial to the pad at this level. Skin flaps were reflected, exposing the flexor sublimis tendon which was dissected from surrounding attachments. The tendon was divided at the level of the radiocarpal joint and then sutured with the barbed suture by the technique already described. The opposite sublimis tendon was exposed, divided and sutured with 40 SWG wire with cutting needles at either end (Pulvertaft pattern) inserted by the standard criss-cross method. The skin was closed with silk.

Immobilisation—The forelegs were immobilised with the legs in 30 degrees of flexion at the radiocarpal joint, using plaster splints reinforced with aluminium strips. These did not cause any distress, and the dogs were able to walk with them.

An attempt was made during the series to dispense with immobilisation and allow weight-bearing immediately. In all cases both suture methods failed. The plain (Pulvertaft) wires snapped, and the barbed sutures either snapped or tore out. There was considerable reactionary haemorrhage and oedema of the wounds. It was clear that no method of suture would be successful under these conditions. The forces were far greater than would be met with in finger tendon suture in man. All later cases in which the fixation of either leg was unsatisfactory were excluded from the series.

TABLE 1

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<th>Barbed suture</th>
<th>Standard suture</th>
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<td>Time in weeks</td>
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After operation the dogs were allowed to bear weight in the splints immediately. They were killed at intervals of one, two, three, and six weeks. In the dogs surviving to six weeks the plasters were removed at three weeks.

The following observations were made on the specimens obtained: the state of the skin healing; the extent of oedema; haemorrhage or fibrosis around the divided tendon; the efficiency of glide of the tendon and the gap if any between the tendon ends. The tendon was then removed from the main specimen. The cause of any failure was determined—for example whether the suture had broken or had torn out. Sections were taken for microscopic study. In some cases the removed specimen was tested in the same way as in the first group of experiments, an increasing load being applied to the suture-tendon junction, and the point of failure measured.

It was found in practice that the suture was either a full success or a failure at the time of examination. Either there was good apposition of the tendon ends, with little oedema or fibrosis, or there was disruption of the anastomosis from either breaking or pulling out of the wires with a greater degree of oedema and fibrosis. Histological examination confirmed
macroscopic observation and gave no additional information. There was no evidence of any reaction around the sutures. The overall results of this series of experiments is that a successful suture was obtained in five out of eight of the cases in which barbs were used and three out of eight of those in which the standard method was used (Table I).

DISCUSSION
The first series of experiments on cadaveric human tendons indicates that the barbed suture has a better grip on tendon than the standard wire in common use. Experiments in dogs gave poor results with both methods but the barbed suture was significantly better than the standard. The forces involved and the problem of post-operative immobilisation of active dogs makes a direct comparison with human surgery difficult. The tendon used does not have a fibrous flexor sheath and it is impossible to assess accurately the degree of adhesion formation which might be expected to occur in the human fibrous flexor sheath.

![Diagram of suture methods](image)

The theoretical extent of adhesion formation in the two methods of tendon suture.

The dog has a similar fibrous sheath and tendon arrangement in the toes, but they are too short to allow the insertion of a barbed suture. The toes of chickens have a very similar anatomy to the human and have been investigated, but the flexor tendons are too small and too flat to allow a barbed suture to be inserted.

On theoretical grounds the barbed suture should be considerably less traumatic than the conventional suture. There is no damage to the external surface of the tendon except a fine puncture at the site of exit of the needle well away from the site of injury. At the site of division there are cleanly cut flat tendon surfaces. The areas where adhesion formation may be expected to occur are shown in Figure 8. With the standard method of suture, trauma to the external surface of the tendon will occur over a total distance of two to three centimetres at the site of injury. With the barbed method there is only a fine linear area of damage.

As has been stated, extremely careful primary tendon suture in the mid-zone of the flexor tendons can give results equal to those of tendon grafting. On the evidence presented it seems probable that the method of employing a barbed suture will allow repair with minimal trauma and with firm apposition of tendon ends.

THE OPERATION IN THE HUMAN

**Repair of flexor digitorum profundus in the mid-zone (Bunnell’s “no-man’s land”)**—The operation is performed under general anaesthesia and tourniquet. A wide exposure of the flexor sheath in the finger is obtained by standard incisions so that 2.5 centimetres of tendon sheath on either side of the injury can be exposed. Flaps are reflected. The site of tendon division is identified, and the sheath is resected for a little over one centimetre on either side of the laceration, allowing resection of the sublimis insertion and adequate access to the divided...
ends of the profundus. A length of the tendon sheath is then excised 2-5 centimetres distal to the site of injury, leaving an intervening segment of sheath undisturbed. The meso-tendon and thus the blood supply of the tendon in these areas is undisturbed and the sheath acts as a pulley. At the proximal opening in the sheath the proximal stump of the sublimis can be

removed. The barbed suture is then inserted by the method previously described. The needle can be made to emerge from the tendon at the sites where the sheath has been resected. A blunt hook passed around the tendon at this point will buckle the tendon and allow the needle to emerge. It must be noted that in most cases when the point of the needle is gripped as it emerges from the tendon surface it cannot be withdrawn through the skin incision. It

should be pushed onwards to emerge through the skin at some distance from the wound (Fig. 9). When the suture has been inserted into both ends and satisfactory coaptation is obtained, the emerging wires are cut off flush with the tendon surface (Fig. 10). The finger is immobilised in the position of rest. At present we immobilise it for three weeks.
Case 1—A nineteen-year-old glass-cutter sustained a laceration on the front of the right wrist dividing the sublimis tendons to the index and middle fingers and the flexor pollicis longus. The initial treatment was by skin suture only and secondary repair was undertaken when the wound was completely healed. In January 1967 a barbed suture was used on the cut sublimis tendon to the middle finger, and the standard criss-cross method using Pulvertaft wire was used for the sublimis to the index and the flexor pollicis longus tendons. Immobilisation was for three weeks and then physiotherapy was commenced. He regained full active and passive movements of all fingers and the thumb.

Four months after injury he still complained of disability from the index finger. His work as a glass-cutter entailed exerting firm pressure on the cutting tool with the finger, the distal interphalangeal
joint being extended. On attempting this with the index finger, the distal joint flexed and he found it difficult to control the cutter accurately. The middle finger did not produce this effect and he could use the cutter without the index finger (Fig. 11). Radiographs were taken of the wrist with the fingers in full flexion and extension, so that the excursion of the tendons could be measured (Fig. 12). The range of movement of the middle sublimis containing the barb was 3.8 centimetres and that of the index sublimis was 2.3 centimetres, a difference in range of 1.5 centimetres. It thus appears both on clinical and radiographic evidence that the barbed suture has given a better result.

Case 2—A woman of fifty-two sustained a laceration at the base of the left little finger dividing the sublimis and profundus tendons. Primary repair of the profundus tendon was performed by the method described, using a barbed suture. The finger was immobilised for nineteen days and then physiotherapy was commenced. Four weeks after starting mobilisation, the range of finger movement was as follows: metacarpo-phalangeal joint, 20 to 80 degrees; proximal interphalangeal joint, 50 to 80 degrees; distal interphalangeal joint, 20 to 45 degrees (Fig. 13). The distance between the tip of the finger and the distal palmar crease in full flexion was 32 millimetres. The excursion of the suture as measured on the radiographs was 19 millimetres. The full excursion of the profundus tendon in the mid-zone of the little finger is 30 millimetres.

These two cases indicate that the claims made for the barbed suture on the experimental evidence are true in clinical practice. Experience so far is too limited to allow any final conclusion to be drawn.

CONCLUSIONS

This method of tendon suture gives a more secure junction than the standard Bunnell criss-cross method using plain wire, and the trauma to the external surface of the tendon is
very slight. The technique is quick and simple, and in multiple tendon injuries in the wrist or palm it may offer great advantage. It allows accurate tendon suture by surgeons not greatly experienced in tendon work. Failure of the primary suture does not exclude a secondary tendon graft.

The method has the disadvantage that a rather wider exposure is required than for ordinary suture, but it is less than that required for tendon grafting. It cannot be used nearer than 2·5 centimetres to the tendon insertion or to the musculo-tendinous junction, but these are not areas where major problems of tendon suture arise.

SUMMARY

1. A new method of tendon suture using a barbed wire is described.
2. Experimental evidence suggests that it may prove superior to existing methods.

I am extremely grateful to Mr W. A. Crabbe whose idea it was to start this investigation, and for his help and encouragement throughout. I wish to thank the Armour Pharmaceutical Company, E.V.D. Engineering, the staff of the Animal Research and Physics Laboratories of Guy’s Hospital, and Miss P. Archer of the Department of Medical Illustration, for their essential help in the various phases of the investigation.

REFERENCES


