April 6, 1965 B. R. BODELL 3,176,316

PLASTIC PROSTHETIC TENDON

Filed Jan. 7, 1963

Fig. 1

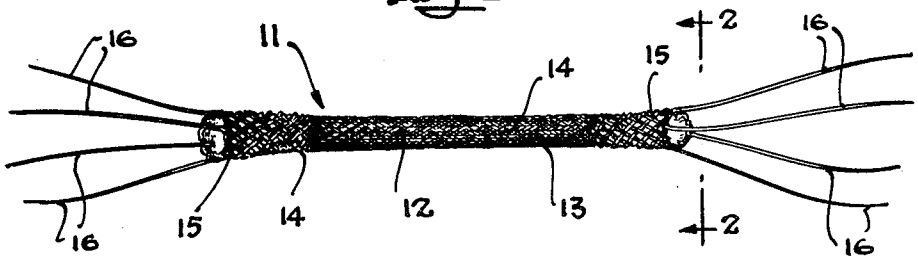


Fig. 3

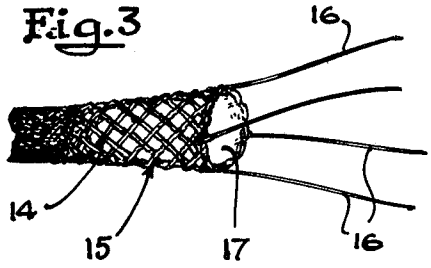


Fig. 2

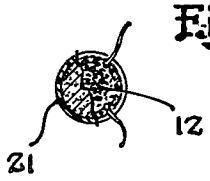
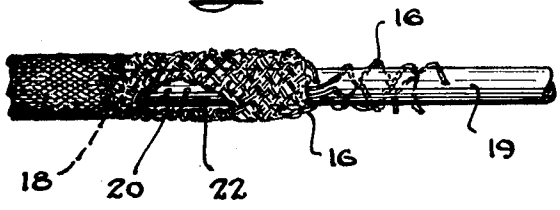


Fig. 4



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PLASTIC PROSTHETIC TENDON

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This invention relates to improvements in plastic tendon prostheses and to methods for effecting improved plastic prosthetic tendon grafts. More particularly, the invention is directed to a tendon substitute which by reason of improved structure, especially end structure, and which, by reason of improved suture methods, obviates, in use, many of the undesirable and objectionable features and the shortcomings of prior art devices and techniques.

Up to the present there have been no completely satisfactory techniques and no uniformly successful procedures by which transected tendons of the fingers could be reapproximated or replaced by autogenous tendon grafts to give normal finger function, particularly when the transection occurs in the area of the middle and proximal phalanges of the fingers. The principal cause for this failure has been adherence of scar tissue (at the site of tendon suture) to the sheath which surrounds the tendon. In many instances, the overall result has been immobilization of the tendon. Attempts to prevent adhesion have met with only limited success, and because of these frequent adhesions, neither primary repeir nor delayed autogenous tendon grafting has yielded consistently good functional results.

The poor results of flexor tendon repair within the flexor tunners of fingers has empasized the need for a satisfactory tendon substitute. However, the use of other tissues and of prosthetic materials has not heretofore provided satisfactory solutions to the problems. The properties of Teflon (polytetrafluoroethylene) have suggested its possible utility as a non-reactive graft. Other materials such as Kel-F (polyfluorotrichloroethylene) and Silastic are also suitable.

Teflon grafts have been used in the prior art, to replace the extensor communis or anterial tibial tendons of dogs. These particular tendons were selected for research, experimentation, investigative work, and testing because, being covered by sheaths where they pass beneath an extensor retinaculum, they present problems which approximate very closely similar problems which must be considered in dealing with other flexor tendons, such as tendons of the fingers in the human.

In prior art plastic prosthetic tendon research and investigations, grafts of closely woven or braided Teflon, coated with liquid Teflon to prevent tissue ingrowth, have been used. A bifurcation Y was provided at each end of the prosthetic tendon. The arms of the bifurcation were flat bars of limited flexibility. These Y bars were sutured to the tendon ends, either with Teflon or with mattress sutures of 4–O silk. While these plastic prosthetic tendons and the suturing techniques used have produced encouraging results in initial investigations, they have not been completely successful in several important applications, particularly when directed to transections in the area of the middle and proximal phalanges of the fingers. Frequently, the failures were due to scar tissue which formed at the site of tenton suture, where the bars of the plastic tendons were sutured to the living tendon. This scar tissues adhered to the sheath which surrounds the tendon and the tendon was immobilized.

The principal object of the present invention is to provide an improved prosthetic tendon which is acceptable to and compatible with human tissues and which will glide freely in the tissues to ensure adequate motion of the part controlled.

Another important object is to provide an improved

end structure for joining prosthetic tendons to natural living tendons or other tissues.

Still another object of the invention is to provide a prosthetic tendon in which the junction of the prosthetic with the living tendon is at a site away from the tendon sheath.

Related important objects of the present invention are to provide improved overall structures for prosthetic tendons; to provide improved methods of joining prosthetic tendons to living tendons and to muscles and other tissues; to provide an improved prosthetic tendon which can be joined with living tendon in a manner to avoid disruption when usual and ordinary stresses are imposed after healing has occurred; to provide a prosthetic tendon which can be used to replace a transected tendon or a fixed tendon; to provide a prosthetic tendon which may be used to replace not only transected tendons, but which may also be used as a replacement in the case of destruction of tendons anywhere in the body where destruction of the natural tendon, as for example through crushing, burns, or missile injuries, has been so extensive as to preclude reapproximation of the severed ends; and to provide a prosthetic tendon which can be connected to a living tendon in a manner to minimize the formation of motion-impairing scar tissue.

Through a technique of tendon transfer to a nonparalyzed muscle, the prosthesis may be used to restore the function of a body part immobilized by muscle paralysis. It may also be used for manipulating parts of limb prosthesis by connection with body muscles through the artificial tendon.

Other objects, advantages, and utilities of the present invention will become apparent as the detailed description continues and upon consideration of the accompanying drawings forming a part of this specification and in which like numerals are employed to designate like parts throughout the same.

FIGURE 1 is a schematic representation of the prosthetic tendon of the invention;

FIGURE 2 is an end view of the prosthesis of the invention taken along the line 2—2 of FIGURE 1;

FIGURE 3 is an enlarged view of an end detail of the prosthesis of the invention; and

FIGURE 4 is a schematic idealized representation of the manner of suture of the prosthesis to a tendon.

Referring now to FIGURE 1, there is shown, for the purpose of illustrative disclosure, a preferred embodiment of the tendon prosthesis of the invention. The prosthesis, indicated generally at **11**, consists of a body in the form of a strong solid or semi-solid flexible shaft **12** having an outer shell or sheath **13** of finely braided, woven, or intertwined inelastic synthetic plastic material such as Teflon, Kel-F, or Silastic, some of the fibers or threads **14** of which continue to and beyond the ends of the principal structure forming an expanding, conically shaped loosely woven casing or sleeve **15** near the ends and terminating, finally, in a plurality of well defined individual or composite strands, threads, or distinct thread-like fibers **16** extending longitudinally beyond the ends of the main portion of the device. Instead of constituting a direct extension of the hollow sleeve or casing **15**, the threads may be anchored at a position within the sleeve **15** or even to the shaft portion of the prosthesis. As illustrated in FIGURE 1, the terminating threads extending outwardly of the ends of the body of the prosthesis proper are four in number. While more than four end threads may be used, if desired, it has been found that four threads are adequate for effecting a good and a balanced suture bond between the prosthesis of the invention and the natural tendon to which it is connected. Three end threads have provided satisfactory suture bonds, and prosthetic tendons having

only two terminal suturing threads have been used successfully, but this particular arrangement may pose special problems in establishing a balanced mechanical stress-supporting bond between the prosthesis and the tendon.

The flexible shaft portion **12** of the prosthetic tendon may be of any desired length, depending upon the particular use and function intended. In cross-section, as depicted in the preferred embodiment of FIGURE 2, the prosthesis is circular. It may be oval or elliptical, and in certain cases a shaft having a double-bowed or a fairly flat cross-sectional configuration may be a satisfactory form. In most instances, the shape of the original natural tendon itself will be adapted for the prosthesis.

The shaft **12** of the prosthetic tendon is of a braided or of a finely woven mesh of a synthetic material such as Teflon, Kel-F, Silastic, etc. This structural form imparts both flexibility and strength to the tendon. Elasticity is to be avoided. The shaft may be essentially solid throughout the major portion of its length, but as described and depicted in the drawings, the shaft is formed to provide a loosely woven hollow cylindrical casing or sleeve **15** at either end (see FIGURE 3). It is into this hollow portion **17** or open cylindrical sleeve that the end **18** of the living tendon **19** is inserted at the time the prosthetic tendon is sutured or otherwise fastened to the natural tendon, as indicated schematically in FIGURE 4.

The loosely woven end structure **15**, as shown in FIGURE 3, provides an open network permitting ingrowth of living tendon fibers **20** to form an integral firm and strong union between the prosthetic tendon and the living tendon **19**. The bond developed through ingrowth of the living tendon into the sleeve **15** of the prosthesis is important in supplementing the mechanical bond provided by suturing the plastic end-threads **16** or fibers of the prosthetic tendon to the end **18** of the living tendon **19**.

While, as is apparent from the above discussion, it is important to encourage ingrowth of natural tendon fibers at the ends of the prosthetic tendon, that is, within the sleeve **15**, it is essential that ingrowth of tissues into the shaft portion **12** of the prosthesis be avoided and that the shaft be smooth and fiber-impervious. The outer sheath **13** is tightly woven or braided to preclude invasion of the shaft by natural fibers and tissues. In order to provide a still smoother and more impervious outer surface a coating or film **21** of solid Silastic or Teflon, etc., is used to prevent the growth of scar tissue into the weave of the shaft.

The overall diameter of the shaft **12** will be dictated by the dimensions of the particular natural tendon with which it is to be associated or which it is to replace in whole or in part. Ordinarily the thickness or the diameter will be in the order of $\frac{1}{16}$ to $\frac{1}{4}$ inch. The length of the loosely woven sleeve or hollowed end portion **15** of the prosthesis should be sufficient to receive the natural tendon segment **22** which is to be inserted. Ordinarily, a length of about $\frac{1}{4}$ to about $\frac{3}{8}$ of an inch is sufficient. For larger tendons, longer sleeves are to be preferred. The terminal threads or strands **16** of the prosthesis

should be long enough to permit their use as sutures for connecting the prosthetic tendon to the natural tendon. A thread length of 3″ to 4″ is preferred for many applications. Shorter lengths may be used and special uses may require longer terminal threads.

While preferred embodiments of the invention have been provided, it will be apparent that numerous modifications and variations thereof may be without departing from underlying principles of the invention. It is therefore desired by the following claims to include within the scope of the invention all such variations and modifications by which substantially the results of this invention may be obtained through the use of substantially the same or equivalent means.

What is claimed is:

1. A tendon prosthesis comprising a solid central section longitudinally aligned between and integrally joined to hollow end sleeve sections, said central section having an elongated substantially inelastic, flexible shaft including a tight mesh lubric plastic outer sheath portion impenetrable to living fibers and scar tissue, each said hollow end sleeve section extending longitudinally from said central section and having an open end to receive therewithin the end of a living tendon, each said hollow end sleeve section being a loose mesh to facilitate ingrowth of living tissue, and each said hollow end sleeve section having a plurality of endwise projecting connection threads for suture into the corresponding tendon for fixing such tendon to the prosthesis while living tissue ingrows in the loose mesh to form a secure bond.

2. A tendon prosthesis comprising a solid central section longitudinally aligned between and integrally joined to hollow end sleeve sections, said central section providing an elongated substantially inelastic, flexible shaft and comprising a large number of interwoven lubric plastic threads defining a tight mesh outer sheath portion impenetrable to living fibers and scar tissue, with only some of said threads continuing endwise in each direction from said central section to constitute each end section as a loose mesh sleeve having a main length region to facilitate ingrowth of living tissue and having an open end to receive therewithin the end of a living tendon, and several of the threads comprising each said hollow end sleeve section continuing therebeyond for suture into the corresponding tendon for fixing such tendon to the prosthesis while living tissue ingrows in the loose mesh to form a secure bond.

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