Technique for and an Anatomic Guide to Forearm Tendon Repair

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Abstract: Forearm lacerations involving muscle bellies are usually treated by repairing muscle fascia. Repair of tendons themselves is stronger and restores normal muscle anatomy better. Tendon repair requires good knowledge of forearm muscle and tendon anatomy. We have made cadaver measurements to produce graphical maps of locations of individual muscles tendons of origin and insertion, some practical guides for finding tendon ends and a simple grasping stitch for intramuscular tendons.

Key Words: tendon injury, extensor tendon, flexor tendon, forearm laceration

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HISTORICAL PERSPECTIVE

Forearm tendon injuries are classified by location (Fig. 1). The flexor aspect of the hand, wrist, and forearm is broken down into 5 zones,[1–4] with zone V representing the area proximal to the transverse carpal ligament. The extensor surface has 9 zones, with zone VIII representing the distal forearm,[2–5] and zone IX representing the mid and proximal forearm (Fig. 1).[3,5] The flexor zone V and extensor zones VIII and IX are primarily muscle bellies. Forearm tendons extend long distances into the muscle belly (Figs. 2A–C),[6] and these segments can be used for suturing.[7] Primary end-to-end tendon repair results in a stronger repair, fewer adhesions, and better functional outcomes.[2,8–10] Lacerations at different forearm levels can result in lacerations of the muscles tendon of origin, both tendon of origin and insertion, or only the tendon of insertion (Fig. 3). Complete transection through only muscle belly is rare in the forearm as in most cases the tendon of origin extends within the majority of the muscle belly length and the tendons of insertion overlap the tendons of origin (Fig. 2).

Common practice for repair of transected forearm muscles is to suture the muscle bellies to the distal tendon end or to suture the muscle bellies together,[5,11,12] often with multiple figure of 8 sutures.[11] However, every effort should be made to locate and reapproximate the cut tendon ends.[2,7,13] This allows for reinnervation of forearm segments distal to the laceration[13] and restores the muscles resting length. The structure and function of the muscle is unlikely to be restored by suturing a tendinous muscle directly to tendon.[7] Suture of the muscle outer fascia to the cut tendon of insertion actually means that the tendon of origin in the outer fascia is sutured to the tendon of insertion, which is technically a tenodesis not a repair.

Forearm muscle tendon lacerations are difficult to repair because the ends frequently retract within the muscle belly and are difficult to find. When the tendon ends have retracted into the muscle belly,[2,10,14–16] the surgeon can use several clues to locate and properly identify the hidden end of the tendon. These techniques include tracking hematoma muscle belly to the tendon cut end,[2,10,17] and observing the laceration angle of the severed tendon ends, tendon diameter, and the location of tendon in relation to other known structures. Retrieval of retracted tendon ends can be done by milking the tendon in a proximal to distal manner,[2,3,10] grabbing the tendon stump with fine-toothed forceps,[10] or extending the incision proximally to gain greater exposure.[2,18,19] Tendon end-to-end surgical repair of lacerated forearm tendons retracted within

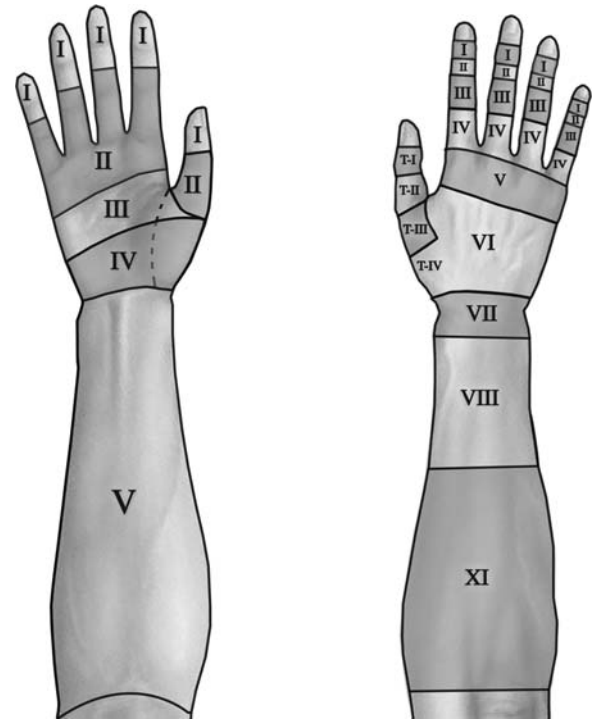

FIGURE 1. Current injury zones for flexor and extensor tendon injuries. Forearm muscle bellies are found in flexor zone V and extensor zones VII and XI.

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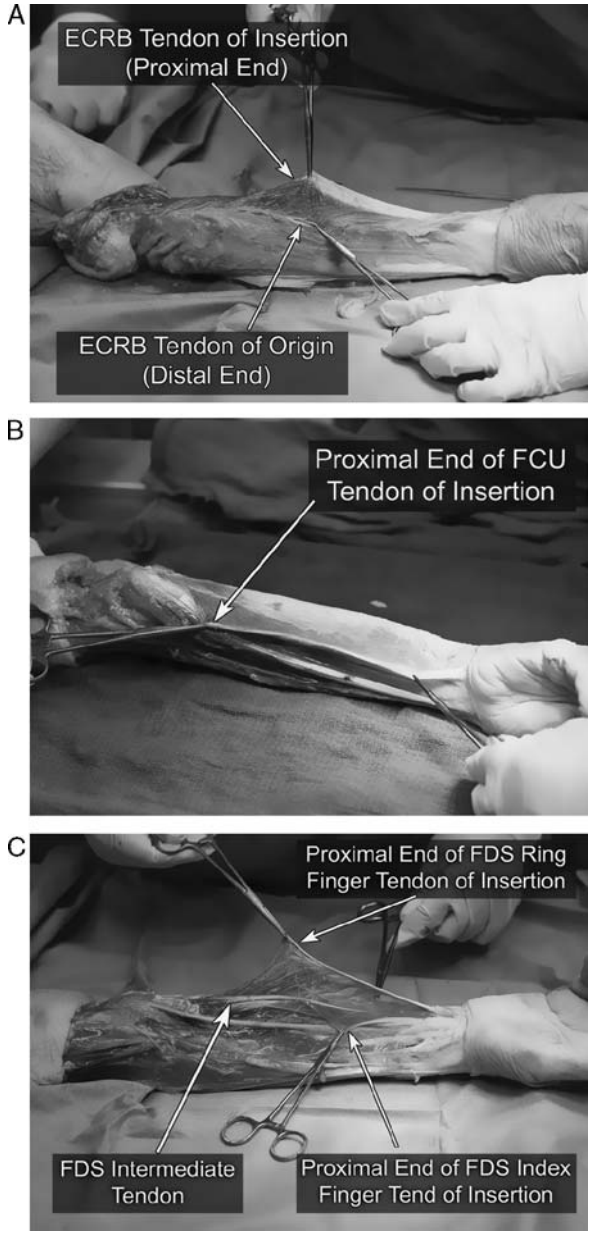

FIGURE 2. The finger flexor and extensor muscles are usually unipennate muscles with both tendon of origin and tendon of insertion extending far into the muscle belly. A, The extensor carpi radialis brevis (ECRB) is a unipennate muscle in the proximal 3/4 of the forearm. The tendon of origin is from the lateral humeral epicondyle and extends in the muscle belly to mid forearm. The tendon of insertion extends to the proximal forearm. B, The flexor carpi ulnaris (FCU) is a large short fiber of muscle. The origin is from the medial epicondyle on the ulna. The FCU has a very long tendon of insertion that extends to the proximal forearm. C, The flexor digitorum superficialis (FDS) is a complicated muscle. The tendon of origin is from the medial humeral epicondyle and extends in the muscle belly through the proximal one-fourth of the forearm. The FDS long muscle belly and a common proximal muscle belly arise from this tendon. The common muscle belly gives rise to the muscle bellies of FDS index finger and little finger. The tendons of insertion come from these muscle bellies. Laceration in the mid forearm can be through both intermediate tendon and tendon of insertion. Both intermediate tendon and tendons of insertion should be correctly matched and repaired.

the muscle bellies requires technical expertize and knowledge of each muscle fiber and tendon anatomy. There is little published information about proximal tendon locations within the muscle bellies proximal to the wrist.

We have made a graphical chart of the probable location of the forearm tendon ends to aid the surgeon. Eight formalin-fixed cadaveric forearms from 8 individuals (4 male and 4 female), 6 right and 2 left were dissected. The humerus midshaft was held in a vise, and a wooden block was placed beneath the distal forearm. The elbow was at full extension, and the wrist was held at approximately 10 degrees of flexion for measurement of forearm extensor tendons and at approximately 20 degrees of extension for measurement of forearm flexor tendons. Metacarpophalangeal (MCP) and interphalangeal (IP) joints were maintained at 60 degrees of flexion to simulate the muscles' resting length. A 3-inch finishing nail was driven into the medial or lateral epicondyle for measurement of the forearm flexor or extensor tendons, respectively. A piece of 14-gauge stranded wire tied to the finishing nail and used to measure the tendons of origin and insertion ends in the forearm.

Each muscle tendon of the flexor and extensor compartment of the forearm was identified by its origin and insertion were traced into the muscle belly with a combination of blunt dissection and a #10 scalpel blade, until the last strand of tendon could be identified.[6] Hemostats were placed at the musculotendinous junctions. The stranded wire was stretched from the epicondyle to each musculotendinous junction along the natural path of the tendon, and measurement of the wire length was taken with a retractable medical measuring tape. The process was repeated 3 times for each tendon. Measurements were taken from the lateral epicondyle to the radial styloid and from the medial epicondyle to the medial aspect of palmar crease for overall forearm length for the extensor compartment and the flexor compartment, respectively. The tendon end-to-epicondyle length was divided by the forearm length to calculate the relative location of each tendon end in the forearm. Nested repeats statistical methods were used to find the error of the method and analysis of variance was used to find the 95% confidence interval for tendon end location in the forearm. Figure 4 and Figure 5 show the locations of the tendons of origin and insertion on the dorsal and volar forearm.

Our measurements show where each of the musculotendinous junction ends is located relative to the length of the forearm. On a measurement scale of 0 to 1, the 95% confidence interval values ($P \leq 0.05$) ranged from 0.01480 for the extensor carpi radialis longus (ECRL) tendon of insertion to 0.12716 for the tendon of origin for the extensor digitorum to the ring finger. The average 95% confidence interval for all tendons was 0.04453. The data we collected showed that the location of the tendon ends for the various forearm muscles can be reliably determined when expressed as percent of forearm length.We describe a technique for locating these tendon ends, a simple grasping stitch for these buried tendons and use the measurements of 8 cadaver forearms to help the surgeons determine where the tendons lie in relation to forearm length and within the individual muscles.

INDICATIONS AND CONTRAINDICATIONS

The technique can be used in any forearm laceration, which involves the tendons or muscle bellies. Contraindications are wounds or patients who are not ready for tendon repair.

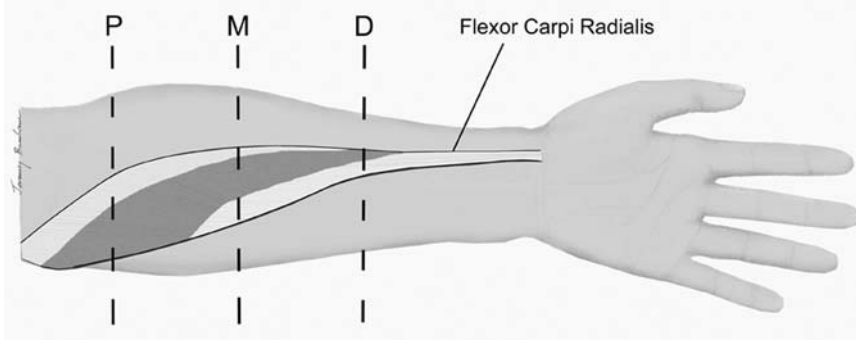

FIGURE 3. The flexor carpi radialis is a typical forearm muscle with a long tendon of origin from the medial epicondyle that extends over half the length of the muscle belly and a long tendon of insertion. A proximal forearm laceration can transect the muscle belly and the tendon of origin (P), a more distal laceration can transect muscle belly and both tendons of origin and insertion (M), and still more distal may transect muscle belly and tendon of insertion (D).

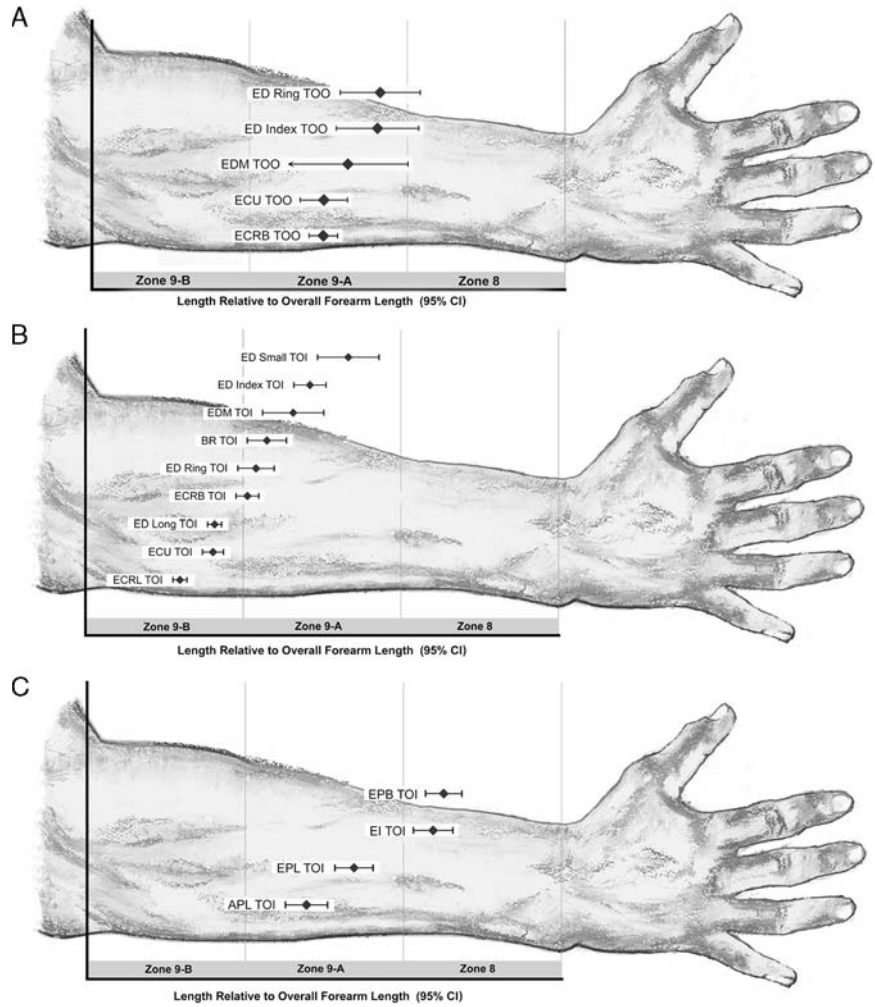

FIGURE 4. A, This is a graphical description of the dorsal forearm level where the distal end of the tendon of origin (TOO) can be found. The tendon ends can be identified and repaired proximal to this level. The TOO will retract distally into the muscle when it is transected. Mainly muscles such as the extensor indicis proprius and abductor pollicis longus take their origin directly from bone or an interosseous membrane and do not have a defined TOO. B, The finger and wrist extensor tendons of insertion (TOI) extend to the proximal one-third of the forearm. Tendon ends can be found and repaired distal to the most proximal extent. The proximal tendon ends usually retract into the muscle but can be identified, retrieved, and repaired. C, The proximal ends of the distal forearm muscles tendons of insertions are shown in this graph.

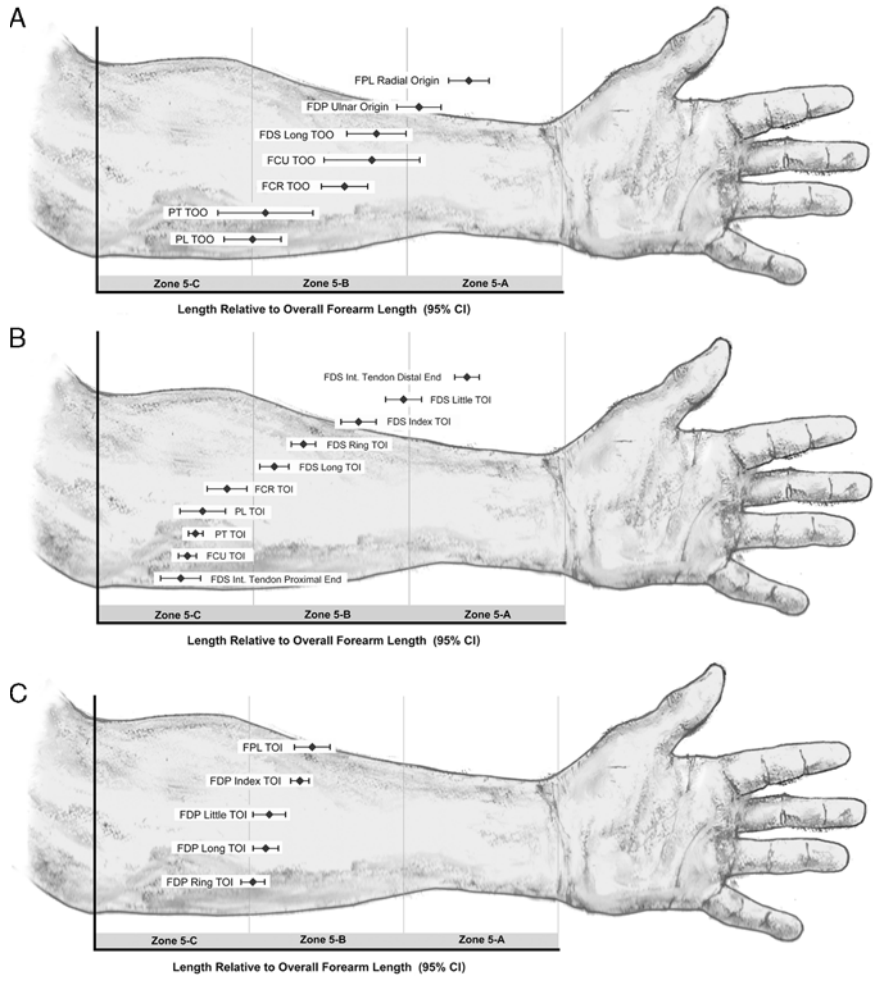

FIGURE 5. A, This is a graphical depiction of the volar forearm level where the distal end of the tendon of origin (TOO) for each muscle can be found. The tendon ends can be identified and repaired proximal to this level. The TOO will retract distally into the muscle when it is transected. The distal forearm flexor muscles such as flexor digitorum profundus and flexor pollicis longus take their origin from the radius and ulna and interosseous membrane and do not have defined TOO. B, This is a graphical depiction of the proximal end of the superficial flexor muscles tendons of insertion (TOI), which extend variable distance into the proximal forearm. The proximal tendon will retract proximally into the muscle when transected, but can be retrieved and repaired. C, The deep flexor muscles TOO extend to the middle on the muscles' volar surfaces. They are easily found and repaired.

Patients should be ready to have a surgery and be ready to change their lives to accommodate the necessary loss of arm use and the rehabilitation necessary for recovery. Wounds should be tidy. Massive injuries such as roll over crush injuries should be debrided, clean and stable before tendon repair is considered. Forearm muscle bellies have a very good blood supply with several vascular pedicles per muscle belly.[20,21] For this reason, the muscle belly blood supply is usually enough for survival. The most distal lacerations may cause ischemia because the tendon blood supply is not as good as that of the muscle itself. In these cases the most distal ischemic muscle should be debrided.

ANESTHESIA

Region block anesthesia is preferred as it provides good perioperative pain relief and muscle relaxation. If a general anesthetic is required, muscle paralysis must be provided.

TECHNIQUE

A tourniquet is applied, but is only used temporarily for hemostasis as needed. The wound is assessed and the table of tendon anatomy is reviewed with reference to the patient's wound and deficits. After the arm is prepped and draped, the wound is explored and lavaged with removal of all foreign material and hematoma. Hemostasis is obtained and the tourniquet deflated if it is used at all. The interval between skin and superficial fascia is dissected proximally and distally to identify the forearm fascia. A modified Tsuge suture is used to repair the tendons (Fig. 6).[22] This suture technique is easier to use within the muscle bellies and is a strong tendon suture. The loop suture can also be used to approximate flat tendons and fascia (Fig. 7).

In volar lacerations, the tendons are identified in layers. Cut muscle tendon units in the volar superficial fascia such as palmaris longus and flexor carpi radialis are identified and sutures are placed in the cut tendon ends. The volar forearm fascia is then opened and the muscle bellies of the superficialis

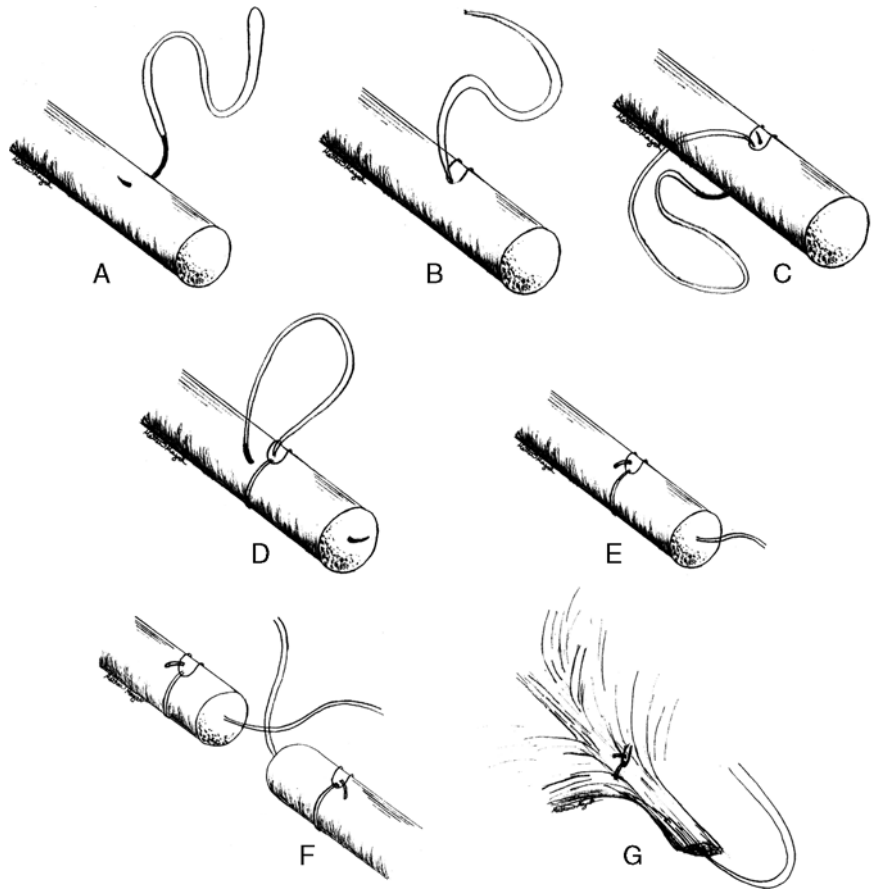

FIGURE 6. A, The Tsuge stitch uses a loop suture.[22] We use a 4-0 loop PDS Ethicon D8747 (3348 Pulliam Street, San Angelo, TA) for flexor and extensor tendon repair. For large tendons such as the FCU, ECRL, and ECRB, we use a 0 loop PDS Z990. The first grasping suture is placed around about one-fourth of the tendon and 1 cm from the cut cast end. B, The needle is placed through the loop and the suture is pulled into place. C, A second grasping loop is passed around about a fourth of the tendon on the other side. The needle passes through the first loop and the suture is pulled through. D and E, The needle is then passed from above the grasping suture out the end of the tendon. F, The same stitch is placed in the other tendon cut end. The ends are then approximated and the sutures are tied together in 1 central tendon knot. Fine suture can be used to approximate the peritenon if necessary. G, This technique can be used to suture tendon within muscle belly without including muscle fiber.

and profundus are located. The proximal tendons are traced in the muscle belly and sutures are placed in the tendinous portion. Tendon ends retracted into the muscle belly can be found by tracing the intramuscular hematoma and gently pulling on the muscle fibers about the hematoma with 2 tissue forceps. Each tendon is sutured as it is retrieved. The suture can then be used to put traction on the muscle belly making it easier to retrieve other tendons. The deep muscle tendon units are similarly identified and sutures are placed. The nerves and vessels are identified. The wrist and fingers are held in flexion and the distal tendon ends are retrieved and examined. If the laceration is in the distal forearm, the blood supply to the distal muscle belly may be interrupted. Muscle belly, which is avascular, is debrided. Muscle belly which bleeds is preserved. Sutures are placed in the tendon ends. Again, the tendons are identified by muscle layer and action. When all the distal tendons have sutures, the wound is reassessed. There should be an equal number of tendons distally and proximally. Further exploration may be necessary to find all tendon ends. The proximal and distal tendon ends are then approximated and tied with a surgeon's knot and 3 square knots. Both strands of each end are tied at once. Fine suture may then be used to tidy the tendon ends. Nerve suture is done after repair of superficialis and profundus tendons but before the more superficial wrist flexors are tied to facilitate exposure. In very proximal volar forearm lacerations, the tendons of origin can be severed. The distal ends will retract distally. Often the tendon of origin has the appearance of a fascia on the muscle belly. This can be sutured with the modified Tsuge suture (Fig. 7) and the cut ends approximated. Repair of the tendon of origin will restore the normal resting length to the muscle fibers and the muscles proximal actions such as the tension of the superficialis on the medial humeral epicondyle, which helps stabilize the elbow joint.

Dorsal forearm lacerations lie near the muscles deep surfaces. The extensor carpi radialis brevis (ECRB) has a long tendon of insertion (TOI) on the muscles' ulnar aspect. The common distal extensor TOI retracts within the muscle bellies. They can be identified and retrieved by tracing the intramuscular hematoma and gently pulling on the cut muscle fibers about the hematoma. The deep layer and first extensor compartment muscles TOI also retract with the muscle belly.

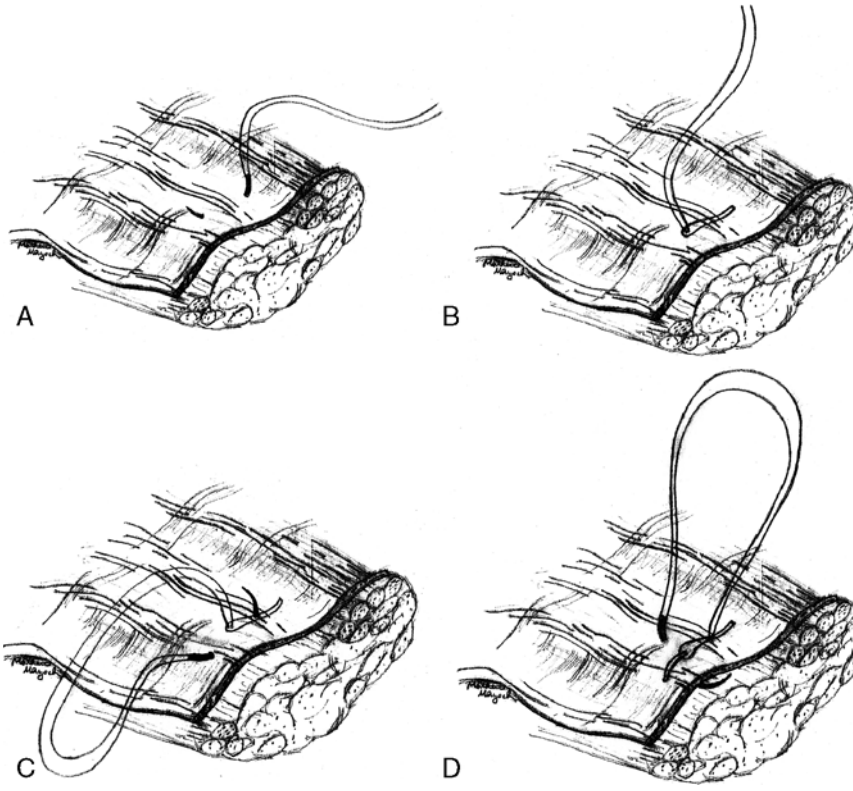

FIGURE 7. A, This modified Tsuge stitch can be used to approximate flat tendons in or on the muscle belly such as tendons of origin. The needle is used to grasp the longitudinal tendon fibers about a centimeter above the cut end. Care is taken to avoid incorporating the muscle fibers in the stitch. B, The first loop is pulled up after the needle is passed through the loop. C, A second loop is around adjacent longitudinal fibers is placed. The needles pass through the first loop. D, This suture is then passed from above the loop out the end of the tendon first above the muscle fibers.

The distal tendons are located, identified by layer and compartment and action and sutures are placed. Again, the number of tendons proximally and distally should be the same. The tendon ends are approximated and the suture is tied.

Nerve and tendon suture are done without tourniquet. Hemostasis is effected at the beginning of the case or as bleeders are encountered and the surgeon should finish with a dry wound. The wound is again irrigated and the skin loosely approximated with a solid absorbable suture. Soft dressings are applied over the wound and the appropriate splint is applied.

ANATOMY OF SELECTED FOREARM MUSCLES

ECRB

The ECRB (Fig. 2A) originates at the lateral epicondyle of the humerus and travels through the common extensor origin. The tendon of insertion begins between the forearm proximal third and the muscle belly itself continues to the middle third of the forearm. The tendon is flat and strong, and very similar to the ECRL. It lies on the dorsal ulnar surface of the muscle belly and travels distally with the tendon of the ECRL.[23] The tendon is approximately 20 cm long in total.[24]

Flexor Carpi Ulnaris (FCU)

The FCU tendon (Fig. 2B) is the most commonly injured tendon in forearm lacerations involving multiple structures.[18] It is a unipennate muscle that extends from its ulnar head almost the entire distance of the tendon, sometimes nearly to the insertion site. The FCU TOI is long and flat, and arises in the anterolateral portion of the muscle.[23] The tendon of insertion extends into the proximal 4/5 of the muscle.[6] The tendon is approximately 20 cm long.[24] The proximal end can be found in the muscle belly by following the hematoma and gently pulling the cut muscle fibers about the hematoma.

Flexor Digitorum Superficialis (FDS)

The FDS (Fig. 2C) is a digastric muscle, with proximal muscle belly and separate distal muscle bellies to the index, ring, and little finger. A common intermediate tendon connects the proximal and distal muscle bellies. The long finger usually has an independent origin and 1 muscle belly.[6,25] The tendon of insertion for the little finger is the shortest, extending to the middle of the distal and middle thirds. In contrast, the tendons of insertion for the ring and long finger extend to the middle third of the forearm. The intermediate tendon spans from the proximal third to the distal third. Lacerations in the middle forearm can transect the tendon of insertion and the tendon of origin.

ECRL

The ECRL originates on the supracondylar ridge of the humerus, just proximal to the lateral epicondyle. The most

distal muscle fibers are in the forearm proximal third. It forms a thick, flat tendon on the lateral and deep surface of the muscle belly.[23] The total tendon length is approximately 26 cm.[24] Lift ECRL to find the TOI.

Brachioradialis (BR)

The BR originates from the lateral aspect of the humerus and lateral epicondyle, and inserts on the radial styloid. The muscle belly extends proximally as far as the middle third of the forearm.[23] The muscle fibers that originate most distally are the shortest and insert most proximally on the tendon, usually at the junction of the proximal and middle thirds of the forearm. The longer fibers originate more proximally on the humerus insert on the most distal end of the tendon where it begins to form a strong, oval tendon. A second tendon system forms as a part of the antebrachial fascia, and serves as an additional insertion for the muscle and keeps the BR muscle from bowstringing.[26]

COMPLICATIONS

Complications of this technique include tendon repair rupture, adhesions, infection, and stiffness as in any other tendon surgery.

REHABILITATION

Flexor Tendon Injuries

Postoperatively the patients are placed in a plaster Kleinert splint and Durran passive flexion active extension exercises are commenced on the day of surgery.[27] This is done to restore independent FDS and flexor digitorum profundus motor function in the fingers and to diminish adhesion formation. The plaster splints are changed to plastic within a week of surgery. Tendon gliding exercises for individual joints and individual fingers with emphasis on maintaining full passive flexion and full IP joint extension. At 3 weeks, the Kleinert splint is replaced by a volar cock up wrist splint and active finger motion is begun while continuing the passive tendon gliding exercises. Light resistive and blocking exercises are started 6 to 8 weeks postoperatively.

Extensor Tendon Injuries

Postoperatively, the patients are placed in a volar splint with the wrist and thumb MCP joints in full extension and the finger MCP joints in 60 degrees flexion. Active and passive IP joint exercises are started on the day of surgery. If there is an extensor tendon repair under the extensor retinaculum, passive MCP extension exercises for the involved digits are added. The volar splint is changed within 3 weeks and active and passive finger and wrist extension exercises are included. Buddy taping the fingers prevents development of individual finger extensor lag. Resistive exercises are started at 6 to 8 weeks postoperatively, combine flexor and extensor tendon injuries. The wrist is splinted in the best position to protect repair nerves, if there is no associated nerve injury.

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