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Flexor Tendon Lacerations in the Hand

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Abstract: Laceration of the flextor tendon is one of the most common injuries seen in the hand. Continuing advances in our understanding of tendon healing and biomechanics have resulted in improved outcomes after flexor tendon repair. A general approach to the management of acute flexor tendon lacerations, including a review of newer surgical techniques, is presented in sufficient detail to give the reader an understanding of the current approach to flexor tendon repair.

Flexor tendon laceration is one of the soft tissue injuries most commonly encountered by the hand surgeon. Recent advances concerning the biomechanics and physiology of flexor tendons and tendon healing have improved our ability to achieve a satisfactory outcome after flexor tendon repair. Nevertheless, many surgeons and their patients continue to be frustrated by post-operative tendon rupture and disabling adhesions. The issues of optimal suture technique and post-operative rehabilitation are under active investigation and continue to generate heated discussions amongst hand surgeons.

Anatomy

The surgeon dealing with flexor tendon injuries should have a thorough understanding of the anatomy of the flexor tendons and tendon sheaths and their biomechanical interactions. These have been covered in sufficient detail by previous authors [17--8,20,28--9,84]. Only certain key points will be highlighted. The flexor digitorum superficialis (FDS) tendons maintain a consistent arrangement in the distal wrist: the tendons to the long and ring fingers lie palmar to those of the index and little fingers. These tendons then fan out into the same plane in the palm. The flexor digitorum profundus (FDP) tendons travel in a single layer deep to the superficialis tendons in the wrist and palm. Just distal to the carpal tunnel, the lumbrical muscles originate from the profundus tendons. Over the proximal phalanx, the FDS tendon splits into two slips around the FDP tendon and then reunite deep to it with decussation of half of the fibers (Camper's Chiasm), before inserting as radial and ulnar slips onto the middle phalanx. The superficialis muscle divides into four bellies in the mid forearm, providing independent flexion of the proximal interphalangeal joints. The four FDP tendons may arise from a common muscle belly, or, less commonly, a radial muscle belly will power the index FDP and an ulnar belly will control the FDP of the ulnar three digits. These tendons flex the distal interphalangeal joints. The flexor pollicis longus (FPL), the lateral-most structure in the carpal tunnel, travels through the thenar muscles and inserts onto the distal phalanx of the thumb, flexing the interphalangeal joint. Differing from the digital flexors, the FPL spans only two digital joints, travels alone in its digital sheath, and has no attached lumbrical muscle.

The pulleys of the finger tendon sheaths consist of a palmar aponeurosis pulley [18,51], five annular pulleys and three cruciate pulleys (Figure 1).

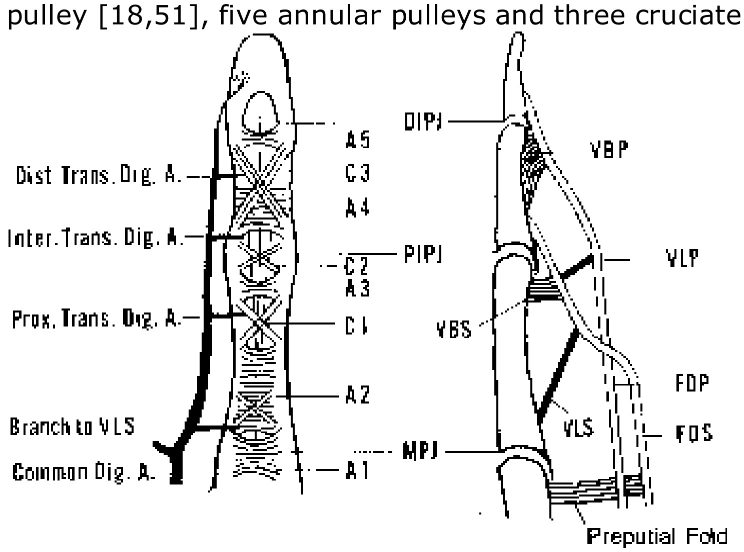


Fig. 1. The fibrous pulley system, the vincula system, and the transverse communicating branches of the common digital artery. (DIPJ, distal interphalangeal joint; PIPJ, proximal interphalangeal joint; MPJ, metacarpophalangeal joint; FDS, flexor digitorum superficialis; FDP, flexor digitorum profundus; VBS, vinculum breve superficialis; VBP, vinculum breve profundus; VLS, vinculum longum superficialis; VLP, vinculum longum profundus) (From Ochiai N, Matsui T, Miyajia N, et al: Vascular anatomy of flexor tendons: I. Vincula system and blood supply of the profundus tendon in the digital sheath. *J Hand Surg* 4:321--330, 1979; with permission).

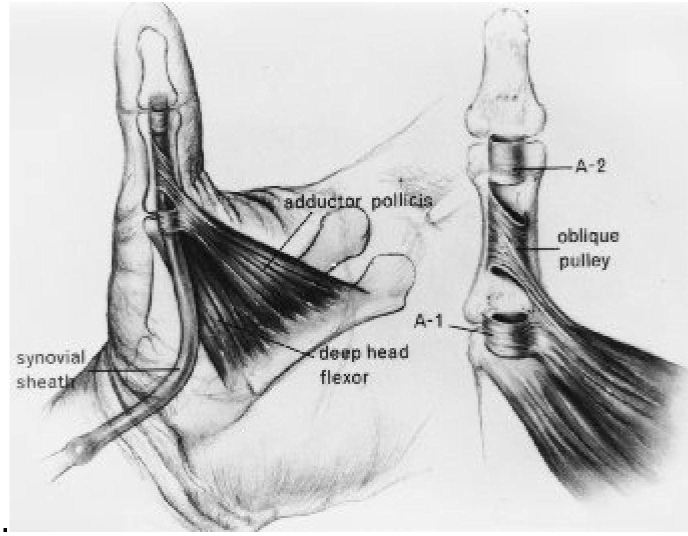
The annular pulleys (A2 and A4 are crucial for normal digital function) prevent tendon bowstringing and provide optimal joint flexion for a given amount of tendon excursion [19,28--29]. The cruciate pulleys provide flexibility of the flexor sheath and provide access to transverse branches of the digital arteries which provide tendon blood supply via vinculum longi and breve [55]. The pulley system of the thumb is different from that of the fingers (Figure 2) the oblique pulley is most important for normal thumb function [20,84]. 

Fig. 2. The fibrous pulley system of the thumb consists of two annular pulleys and the more important oblique pulley. (From Doyle JR, Blythe WF: Anatomy of the flexor tendon sheath and pulleys of the thumb. *J Hand Surg* 2:149--151, 1977; with permission).

Flexor tendons are nourished both by the vincular system and the synovial fluid within the tendon sheath. Clinical and experimental studies have demonstrated the importance of both diffusion and perfusion [2,5,49,50]. The relative significance of these two system in the normal and repaired flexor tendon has yet to be clarified.

Injury

The goal of flexor tendon repair in the hand is a meticulous repair strong enough to allow early motion, which, in turn, will encourage intrinsic tendon healing and restore digital function. There are a number of factors which can affect the outcome of flexor tenorrhaphy. Bony or soft tissue injuries associated with a flexor tendon laceration may have a negative impact on prognosis. Increased peri-tendinous adhesions will develop if the tendon has also sustained a crush injury, whether iatrogenic or trauma-related. Repair of concomitant nerve or arterial injury will affect immmediate postoperative mobilization, and may adversely affect ultimate hand function. A concomitant fracture can lead to increased adhesions at the injury site and influence postoperative rehabilitation if rigid fixation cannot be obtained.

Historically, the level of flexor tendon injury was important in determining treatment options (e.g. primary repairs were rarely performed in zone II, "no-man's-land") [11,75]. Verdan's original division of the flexor tendon system into regions has since been modified, resulting in a 5 zone classification (Figure 3) [37,77].

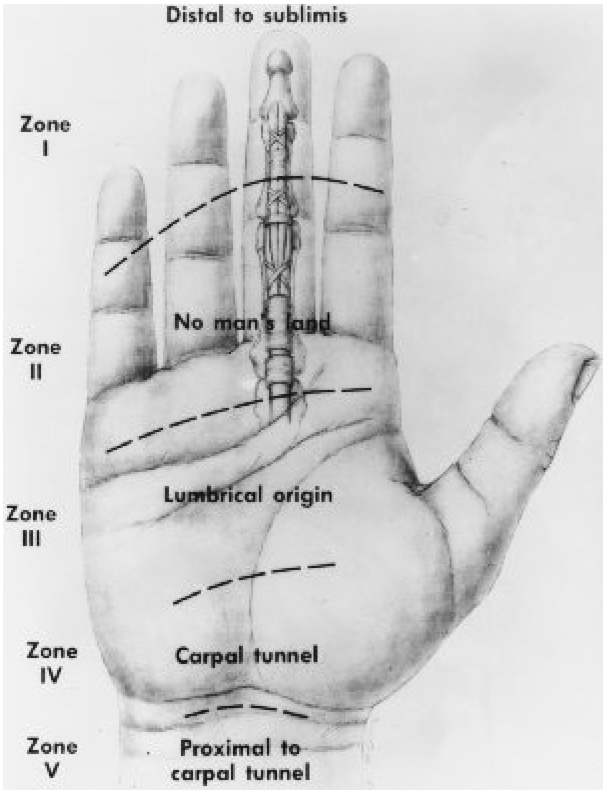


Fig. 3. Flexor zones of the hand. (From Milford L: Tendon injuries. In: Crenshaw AH (ed). Campbell's Operative Orthopaedics, edition 7, St. Louis, CV Mosby Co, 1987; with permission).

Currently, primary or delayed primary repair is recommended for all flexor tendon lacerations regardless of location. However, knowledge of the zones is still helpful, as a worse prognosis is associated with injuries in zones II and IV, due to the propensity to form adhesions between tendons within a confined space.

Immediate or delayed primary repair (7--10 days) is now advocated for most acute flexor tendon injuries. The advantages of early repair include less extensive surgery, decreased periods of disability, and restoration of the tendon to its normal length [76]. Many authors would agree that partial lacerations should be explored early, as these can go on to rupture any time after injury [7,38,66]. Tendon lacerations in Zone II should also be treated relatively early to prevent excessive retraction of the proximal stump. Contraindications to primary repair of flexor tendons include severe soft tissue injuries with crush or avulsion, segmental tendon injuries, grossly contaminated wounds, or loss of palmar skin. Extensive damage to the pulley system requires pulley reconstruction in conjunction with one or two stage tendon grafting [19,35,44,67].

Diagnosis

In the cooperative patient, diagnosis of flexor tendon lacerations should be relatively straightforward. An intact FDS produces independent active flexion of the proximal interphalangeal joint while the other digits are maintained in full extension. One can be fooled when evaluating the small finger, as the FDS in this digit may be absent in 21% of patients, with 26% unilateral [4]. FDP function is evaluated by active flexion of the isolated DIP joint of the finger and IP joint of the thumb indicates intact FDP and FPL tendons, respectively.

In the unconscious or uncooperative patient, an abnormal resting posture of the digits may indicate flexor tendon injury (Figure 4a).

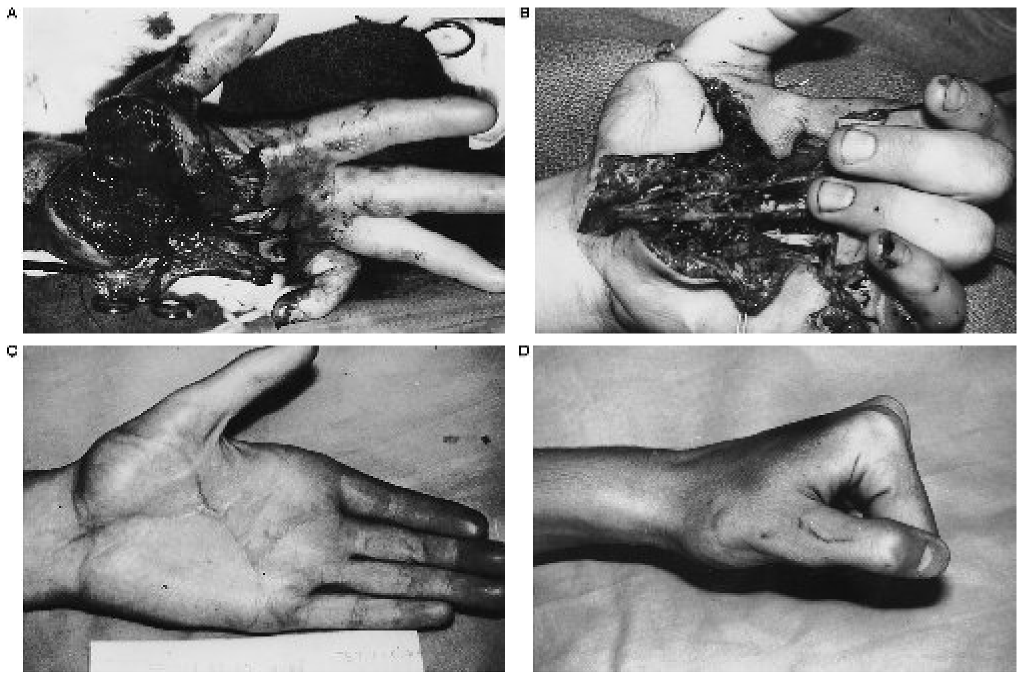


Fig. 4. Severe multi-tendon injury to left hand. (A) Deep avulsion laceration in the palm resulting in flexor tendon injuries to thumb, index, long and ring fingers. Note the normal flexed posture of small finger and absence of flexion cascade of other digits. (B) Restoration of flexion to all digits after repair of flexor tendons, which can now be seen longitudinally traversing the palmar wound. (C and D) Functional range of motion achieved after intensive hand therapy.

Lack of digital flexion when squeezing the flexor muscles in the forearm or absence of a tenodesis effect with flexion and extension of the wrist should alert the examiner to the possibility of flexor tendon injury. In more extensive injuries, the physician may not be able to arrive at a complete and accurate diagnosis until surgical exploration of the wound.

A partial tendon laceration may be present if the patient experiences pain at the site of injury when performing these maneuvers against gentle resistance. There are currently no good non-invasive techniques for diagnosing a partial laceration; many of these are therefore diagnosed intraoperatively.

Surgical Repair

Flexor tenorrhaphy is performed with loupe-mag-nification under regional or general anesthesia in a bloodless field. The surgeon performing the technically more difficult repairs in zones I to IV, should be well-versed in the intricate anatomy of the flexor tendon system, as well as experienced in the atraumatic surgical techniques advocated by Bunnell [11--13]. The traumatic wound is extended with either a mid-lateral or palmar zigzag (Bruner) incisions [8,9]. The Bruner incision offers better visualization, while rehabilitation may be improved with the mid-lateral incision, as the flexor surface is not disturbed.

The principles of atraumatic handling of the soft tissue and meticulous hemostasis should always be followed when operating in the hand; nowhere is this more important than in the confines of the fibro-osseous tunnel in zone II. Some or all of the sheath must be incised (in an L-shaped fashion) or resected to provide optimal exposure of the tendon ends. A2 and A4 pulleys must be preserved, and attempts should be made to leave all annular pulleys undisturbed. Under ideal circumstances, vincula may prevent retraction of the proximal tendon stump. If this is not the case, a number of techniques may be used for tendon retrieval. The wrist and metacarpophalangeal joints should be maximally flexed. The flexor muscle bellies may be milked manually or with firm application of an Esmarch bandage from proximal to distal. If these maneuvers are ineffective, a tendon retriever may be passed proximally under the A2 pulley. The surgeon should not persist beyond one or two attempts, as significant iatrogenic trauma to the tendon sheath and tendon ends may occur, resulting in significant postoperative adhesions. Distally lacerated flexor tendons rarely retract beyond the mid palm. The proximal tendon end may be found through a separate oblique incision just proximal to the A1 pulley. A pediatric feeding tube may be passed through the sheath from the distal wound into the proximal incision, where the tendons are sutured to the catheter. If the proximal tendon stump has not retracted beyond the A1 pulley, it can be left in place and sutured side-to-side to the catheter, as recommended by Sourmelis and McGrouther [68]. The catheter, followed by the tendons, is then pulled distally through the pulley system. The relationship of the profundus and superficialis tendons must be maintained during this part of the procedure. Proper rotational orientation is obtained by placing the tendon surface with vincular remnants in the dorsal position. Further retraction of the tendons may be prevented by transfixing them to the skin and A2 pulley with a 25 gauge hypodermic needle.

The ideal tendon repair should allow ease of suture placement with minimal tendon handling, a smooth repair site with minimal gap formation, and sufficient strength of both the suture material and entire repair to allow early mobilization. A variety of suture material and techniques have been described which allow these goals to be met [30--32,34,65,73,81]. Most surgeons prefer a grasping core stitch with 3-0 or 4-0 synthetic braided suture, followed with a running epitenon suture to invaginate tendon edges and prevent triggering on the sheath [31,32]. This epitendinous suture prevents gap formation and increases the strength of the tendon repair [43,78]. A number of studies have demonstrated that the strength of the repair is proportional to the number of core suture strands crossing the laceration site [42,63,65]. The strength of these repairs is increased enough to allow earlier active motion, and are therefore gaining popularity at many hand centers [70].

For the majority of flexor tendon repairs, I prefer a modified Kessler-Tajima core stitch with 3-0 braided Dacron, followed by a 6-0 nylon locked, running circumferential stitch [74]. The core suture is placed in the palmar half of the tendon in order to preserve the dorsal blood supply. As recommended by Strickland, this is augmented with a more palmarly placed horizontal mattress stitch to create a four-strand core repair (Figure 5) [70].

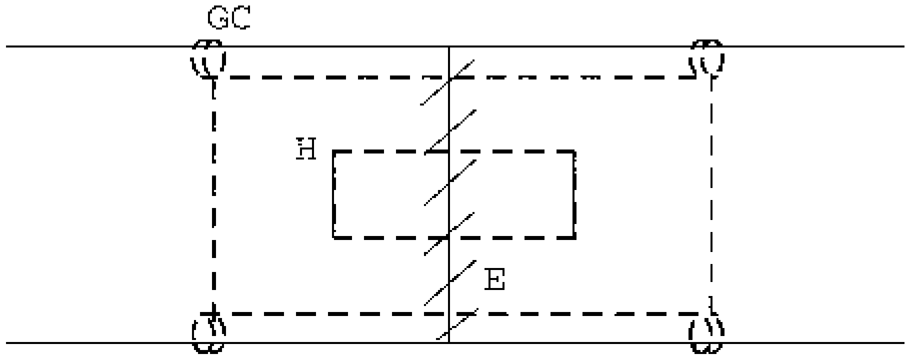


Fig. 5. Four-strand repair preferred by the author, a variation of the Indiana technique [70]. (GC, grasping core; H, horizontal mattress core; E, running or locked epitenon).

For lacerations through the superficialis slips, a simpler horizontal mattress stitch, as described by Nicolodani, is effective [54]. While controversial in the past, repair of both the profundus and superficialis tendons is now common practice. Repair of both tendons restores a normal flexor mechanism, providing increased strength and more independent digital function [37,41,77].

Once the tendons have been repaired, the 25-gauge needle preventing retraction may be left in place until surgery is concluded (if it has been previously placed through both skin and sheath). This prevents accidental disruption of the repair during closure. After repair of associated soft tissue injuries, the skin is closed with 5-0 nylon. A bulky compressive dressing is applied, and the hand immobilized in 20%--30% wrist flexion, 60%--80% MPJ flexion, and gentle flexion of IPJ.

Repair of the tendon sheath remains controversial. The theoretical benefits of sheath closure include improved tendon nutrition through synovial fluid production and restoration of an important component of the gliding mechanism [48,58,59,72]. However, repair of the synovial portions of the tendon sheath are technically demanding and, through narrowing, may actually restrict tendon excursion. Despite a series of experimental and clinical studies, no significant advantage of sheath closure has been demonstrated [26,47,60,61,64].

Special Circumstances: FPL, FDP, Partial Lacerations

The unique anatomy of the thumb flexor mechanism slightly alters the approach to lacerations of the FPL. The tendon is more likely to retract, as it has only one vinculum and no attached lumbrical muscle. A separate proximal incision in the wrist is indicated if the proximal tendon end is not readily apparent in the wound. A small longitudinal incision made over the radial aspect of the wrist proximal to the transverse carpal ligament provides ready access to the tendon stump. It can then be advanced through the thenar muscles and into the tendon sheath using the retrograde catheter method.

FDP lacerations in zone I may require a different method of repair if there is insufficient length of the distal stump. The distal sheath should be opened, preserving the A4 pulley. If the finger was flexed at the time of injury, the DIP joint may have to be flexed in order to deliver the distal tendon stump into the wound. If less than one centimeter of this distal stump is present, the surgeon should consider inserting the profundus tendon directly into the distal phalanx. The palmar plate of the distal interphalangeal joint should be protected during this procedure. The palmar cortex is prepared with a curette or small osteotome to create a bleeding surface which will encourage tendon-to-bone healing. Two oblique holes along the radial and ulnar aspects of the palmar surface are drilled with a Keith needle, from palmar-proximal to dorsal-distal. The needles should exit through the sterile matrix of the nail. 3-0 polypropylene is passed through the tendon end in a crisscross fashion, brought out through the distal phalanx with Keith needles, and tied snugly over the nail with a button. This pull-out suture and button are removed at six weeks.

Controversy persists regarding optimal management of partial flexor tendon lacerations. Some advocate tenorrhaphy to minimize complications, while others feel that repair may weaken healing tendons [81,83]. Experimental studies have produced mixed results; a modified Kessler core stitch does appear inferior to epitenon repair or no repair in partial lacerations of less than 60%-70% of tendon diameter [6,16]. Complications including triggering, rupture, and entrapment increase with larger partial transections and beveled lacerations [66]. I prefer to repair partial transections which are greater than 50%-60% of tendon diameter. Smaller lacerations are left undisturbed or trimmed if the tendon edge seems prone to entrapment or triggering.

Rehabilitation

Until the 1970s, it was believed tendons healed only through extrinsic cellular invasion from peripheral tissues [52,56,57,62]. It is now commonly accepted that flexor tendons heal by an intrinsic cellular mechanism which is promoted by early controlled mobilization [22,24,27,46,69]. All of these techniques require close supervision by a therapist as well as a cooperative and motivated patient.

The specific rehabilitation protocol depends on the specific suture technique used as well as individual surgeon preference. All involve use of a dorsal splint for the first six weeks maintaining 20%--30% of palmar flexion at the wrist and 60%--70% of palmar flexion at the metacarpal phalangeal joints with extended interphalangeal joints. When flexor tendon lacerations have been repaired with a two-strand core suture, one of three basic techniques for early controlled mobilization is employed. Kleinert and associates popularized dynamic splinting, in which a rubber band attached to the finger nail provides dynamic passive flexion against which the patient actively extends [36,46]. Continuous passive motion (CPM) may result in improved digital motion in some surgeons' hands [10,25]. We use a modified Duran protocol which consists of passive flexion and active extension exercises of each interphalangeal joint within the splint, with progression to gentle active motion and subsequent resistive exercises [14,21,69].

When a four- or six-strand tenorrhaphy has been performed, patients may begin an early active motion program in a closely supervised setting. These combine passive techniques, composite digital motion, and light active flexion with wrist extension. Early experience with this protocol appears promising for improving overall hand function compared to strictly passive motion techniques [15,70].

Complications

Triggering, tendon rupture, and bow-stringing have all been reported following flexor tenorrhaphy [45]. Triggering often responds to a therapy program including ultrasound and scar massage, but may require exploration at the injury site. Early tendon rupture after sharp lacerations is best treated with re-exploration and repair in the compliant patient. Significant bow-stringing may require pulley reconstruction.

While early controlled mobilization has decreased the incidence of tendon adhesions, they still remain the most significant problem after flexor tendon repair. If a patient fails to progress after three to six months of therapy, they may require surgical tenolysis [79,80]. Pharmacological attempts at reducing adhesions have met with varying degrees of success and remain investigational [3,33,39,40,53,71].

Conclusions

Current surgical techniques and rehabilitation programs have significantly decreased the tendon ruptures and adhesions which frustrated early attempts at repair. Nevertheless, the ability to regain normal digital motion and strength after flexor tendon laceration remains a challenging goal. Close communication between the patient, surgeon, and hand therapist is crucial in achieving acceptable function. A thorough understanding of tendon anatomy and physiology, attention to atraumatic surgical technique, and a supervised post-operative rehabilitation protocol will ensure satisfactory results in the majority of cases.

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