Evidence-Based Medicine: Surgical Management of Flexor Tendon Lacerations

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Learning Objectives: After reading this article, the participant should be able to: 1. Accurately diagnose a flexor tendon injury. 2. Develop a surgical approach with regard to timing, tendon repair technique, and rehabilitation protocol. 3. List the potential complications following tendon repair.

Summary: Flexor tendon lacerations are complex injuries that require a thorough history and physical examination for accurate diagnosis and management. Knowledge of operative approaches and potential concomitant injuries allows the surgeon to be prepared for various findings during exploration. Understanding the biomechanical principles behind tendon lacerations and repair techniques aids the surgeon in selecting the optimal repair technique and postoperative rehabilitation. (*Plast. Reconstr. Surg.* 140: 130e, 2017.)

Flexor tendon lacerations are common injuries managed in a plastic surgery and hand surgery practice. Understanding the appropriate workup and management can allow for an optimal outcome of this difficult problem. Acknowledging the limitations in best available evidence and the variations in treatment approaches is important in creating a patient-centered treatment plan. The treatment principles, surgical techniques, and rehabilitation options are discussed to optimize patient function.

PREOPERATIVE EVALUATION

Patient History

On evaluation of the patient with a flexor tendon injury, a thorough history can help guide management. For example, the young musician that sustains a flexor tendon injury and presents acutely with the inability to perform may be managed differently than the infirm patient that presents with a chronic flexor tendon laceration and minimal disability. Other concomitant injuries, functional demands (handedness, occupation), and expectations can influence the surgeon's preoperative discussion with the patient regarding outcomes after treatment of a flexor tendon laceration.

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Physical Examination

Preoperative examination of the injured limb is by far the most critical aspect of managing a flexor tendon laceration, as it will dictate the surgeon's primary and secondary operative plans, guide the informed consent process with the patient, and minimize unanticipated intraoperative findings or unexpected variation in treatment. Physical examination includes evaluating the resting posture of the hand. Loss of the normal cascade with extension of the injured digit is suggestive of flexor tendon injury (Fig. 1). Likewise, loss of the tenodesis effect (finger extension with passive wrist extension, and finger flexion with passive wrist extension) or an abnormal forearm compression test (lack of finger flexion with gentle compression of the flexor tendon muscle bellies in the forearm) will confirm this suspicion. Isolated testing of the flexor digitorum superficialis, flexor digitorum profundus, and flexor pollicis longus of the thumb will help differentiate which tendon(s) have been injured. To isolate flexor digitorum superficialis function to

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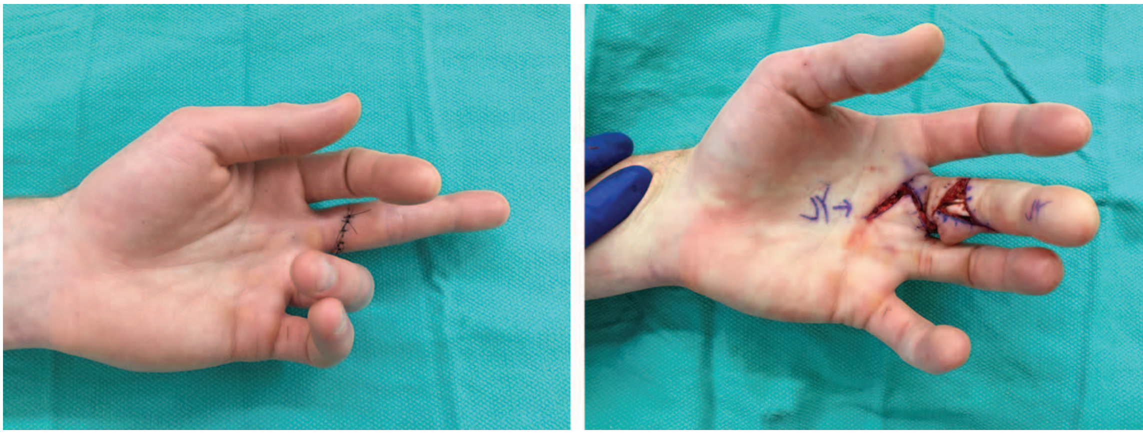

Fig. 1. (*Left*) Loss of the normal cascade with extension of the middle finger is suggestive of a flexor tendon injury. (*Right*) Return of the normal cascade after repair of the flexor tendon injury.

one digit, the adjacent fingers are manually held with all joints in extension. Flexion of the digit is secondary to firing and pull-through of the flexor digitorum superficialis tendon (not the flexor digitorum profundus) because the examiner is preventing firing of the flexor digitorum profundus tendon by keeping all adjacent fingers in extension (therefore preventing flexor digitorum profundus tendon excursion caused by its common muscle belly (Fig. 2, *left*). The surgeon should then examine the flexor digitorum profundus tendon by manually keeping the proximal interphalangeal joint in extension and asking the patient to flex the involved distal interphalangeal joint (Fig. 2, *center*). Although the flexor digitorum profundus tendons have a common muscle belly, normal anatomical variants such as having independent flexor digitorum profundus to the index or middle fingers, or absent flexor digitorum superficialis to the small finger, can alter the examination. Studies have recently shown that ultrasound[1–3] and magnetic resonance imaging[4] are highly accurate at identifying tendon lacerations (partial or complete), although with a good physical examination, the surgeon should typically not require these ancillary imaging modalities.

The zone of injury of the laceration may also help guide the surgeon to which tendon may be lacerated (Fig. 2, *right*). In the fingers, when the laceration is in zone 1, (distal to the flexor digitorum superficialis insertion), only the flexor digitorum profundus is susceptible to injury. In zone II (between the A1 pulley/distal palmar crease and the insertion of the flexor digitorum superficialis tendon/mid middle phalanx), both the flexor digitorum superficialis and flexor digitorum profundus are close together and susceptible to injury. Zone III (between the distal end of the transverse carpal ligament and the A1 pulley/distal palmar crease) contains tendons and neurovascular structures to all digits, typically leading to injuries to multiple structures and multiple digits when a laceration occurs there. Because of the

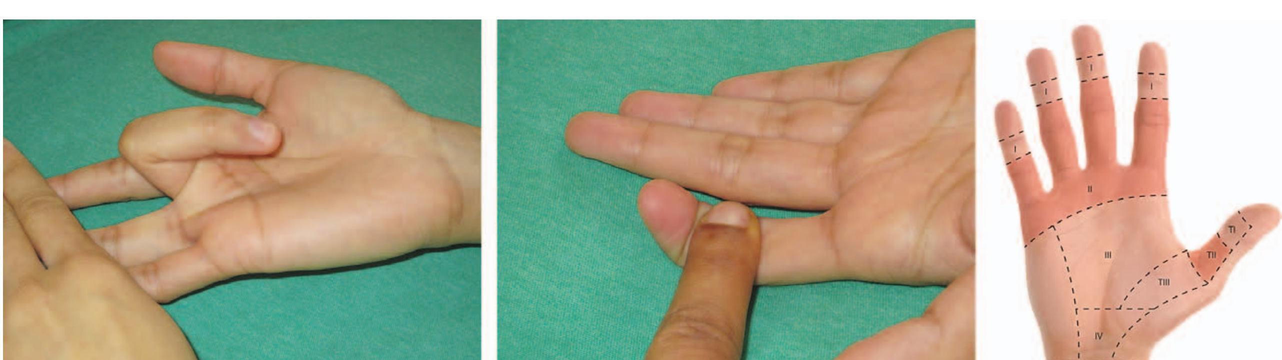

Fig. 2. (*Left*) Testing the flexor digitorum superficialis and (*center*) flexor digitorum profundus. (*Right*) Zones of injury on the volar hand. (Reprinted with permission from Kamal R, Weiss AP, eds. *Comprehensive Board Review in Orthopaedic Surgery*. New York: Thieme; 2017.)

protection imparted by the thick transverse carpal ligament over zone IV, tendon injuries are less common here, unlike zone V, which is proximal to the transverse carpal ligament.

The character of the tendon injury (e.g., crush versus sharp and clean versus contaminated) is important in surgical planning of the tendon repair and management of the soft tissues. A crush injury that leads to destruction of the pulleys in zone II will be treated differently than a sharp laceration of the flexor digitorum superficialis and flexor digitorum profundus tendons in the same area. Likewise, devitalized tissue or tissue loss predisposes to infection and scarring and will need to be considered during tendon repair. Evaluation of the tissue also allows for surgical planning of potential flaps needed for wound coverage.

A thorough neurologic examination, including two-point discrimination testing of the radial and ulnar digital nerves, should be considered to ensure that any injuries are identified and subsequently addressed during surgery. Likewise, pulses in the wrist and capillary refill in the digits should be evaluated, and a handheld Doppler probe or pulse oximeter may also be placed on the digit to evaluate for ischemia.

Acute Management

After the history and physical examination and evaluation of the radiographs, the acuity of the injury is established. In patients with distal limb ischemia, arterial insufficiency mandates emergent exploration and vascular repair and should occur at the same time as the management of the flexor tendon laceration. In the polytraumatized or mangled extremity, the need to manage the soft tissues, arterial injuries, or open skeletal injuries will dictate emergent surgical management. There is a paucity of literature that informs the surgeon on the optimal timing of isolated flexor tendon repair. Animal studies have suggested that urgent repair (<24 hours) may be ideal,[5,6] although clinical studies are lacking. Stone and Davidson have shown equivalent infection rates of early and late repairs.[7] Tendon repair should occur within 3 weeks of injury,[8–11] as over time the tendon ends become distorted, the sheath scars, the muscle-tendon unit shortens, and adhesions will form.[12] Beyond 3 to 4 weeks, primary repair is typically not possible because of proximal tendon swelling and tendon retraction.[13] Once the examination is complete, the extremity can be splinted to minimize retraction of the tendon edges.

SURGICAL TREATMENT

Surgical management of flexor tendon lacerations should be planned based on the preoperative physical examination. This includes equipment needed for tissue rearrangement, fluoroscopy with necessary hardware, microsurgical instruments, and if indicated, nerve conduits/allograft. The surgeon should ensure that these are available, as identifying concomitant injuries during exploration is not uncommon. A tourniquet may be used for hemostasis during exploration and tendon repair, and released for vascular anastomosis. In general, primary repair is completed in the setting of a clean-cut wound, or one with minimal crush injury.[12] Relative contraindications include altered soft tissues that could lead to scarring and tendon adhesions, including severe soft-tissue injury or contamination, infection, unstable fractures, or segmental tendon loss.

Anesthesia Considerations

Flexor tendon repairs are typically performed under general or regional anesthesia. Recent evidence, however, has shown that "wide-awake" surgery with local anesthesia with epinephrine may be advantageous.[14] Lalonde has previously reported using local anesthesia alone for flexor tendon repair.[15] Higgins et al. demonstrated the ability of patients to participate intraoperatively after tendon repair.[16] The authors were able to evaluate active motion for gapping, tendon gliding, entrapment, and knot entrapment while still in the operating room. Comparative studies of this technique showing noninferiority or superiority compared with traditional anesthesia are yet to be published in the literature.

Surgical Incisions

The surgical approach to a flexor tendon injury should be made anticipating proximal or distal extension of the approach and for the potential of harvesting a graft. Planning of the incision in this way ensures that the ends of the tendon may be visualized and any concomitant injuries may be addressed. In addition, anticipating an extensile approach may ensure appropriate flap creation to minimize the risk of flexion contractures or wound healing issues that may predispose to infection. A Bruner type of zig-zag incision may be used in the finger and in the palm[17] (Fig. 3). In the finger, this allows for exposure without longitudinal incisions over flexion creases, and crosses the neurovascular bundles. Transverse incisions at the corners of the zig-zag

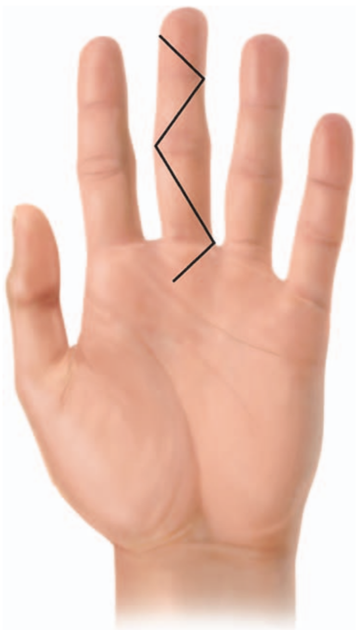

Fig. 3. Bruner zig-zag incision over the volar digit. (Reprinted with permission from Kamal R, Weiss AP, eds. *Comprehensive Board Review in Orthopaedic Surgery*. New York: Thieme; 2017.)

may also be used as a V-to-Y advancement to assist in lengthening the wound and closure. A midlateral incision may be used instead of the Bruner type of incision to avoid crossing the volar surface of the digit. This incision is carried out over the neurovascular bundle on the lateral aspect of the digit. In clinical practice, the orientation of the traumatic wound and its location play the greatest role in the design of the incision.

Operative Approach

After the wound is extended, cleansed, explored, and débrided of nonviable tissue, dissection is typically developed from known areas with normal anatomy (uninjured tissues) to the traumatized areas. This allows for identification of normal tissue planes and neurovascular structures. Based on the preoperative radiographs, the surgeon completes skeletal fixation if necessary. This allows for a stable platform for tendon repair and neurovascular repair when needed. After skeletal stabilization, the tendon wound edges are prepared for repair.

There are five annular pulleys (Fig. 4) that serve to prevent bowstringing of the flexor tendons when activated. This increases the mechanical advantage of the tendons by keeping them close the axis of rotation of the joints of the finger. The surgeon should make every attempt to maintain these pulleys because of the biomechanical advantage they impart on finger flexion.[18,19] Tendon repair should be attempted between the annular pulleys when possible. If the laceration is not located in such a way that this is possible, the pulley may be vented, by releasing a portion (up to 50 percent) of the pulley to allow for repair. If access and repair are still not possible, the A1, A3, or A5 pulley may be sacrificed. Although it was initially accepted that disruption of greater than 50 percent of the A2 or A4 pulley requires reconstruction,[20,21] some studies have shown that up to 100 percent of either the A2 or A4 pulley does not need to be preserved, provided that the other is intact.[12,18,22]

Following exploration, the exposed tendon edges are trimmed back to healthy tissue. Any injury to the tendon that is less than 60 percent may typically be managed without repair.[23] Instead, the surgeon must ensure there is no triggering of the tendon during range of motion. If there is triggering evident, the tendon should be débrided, or if greater than 60 percent of the tendon is involved, it should be repaired. When the tendon requires surgical repair, the proximal and distal ends of the tendon are brought into the wound. Because the digit and wrist may have been flexed at the time of injury, the tendon edges may be retracted away from the wound. The extrinsic blood supply to the flexor digitorum superficialis and flexor digitorum profundus tendons is carried through the short and long vincula. When the

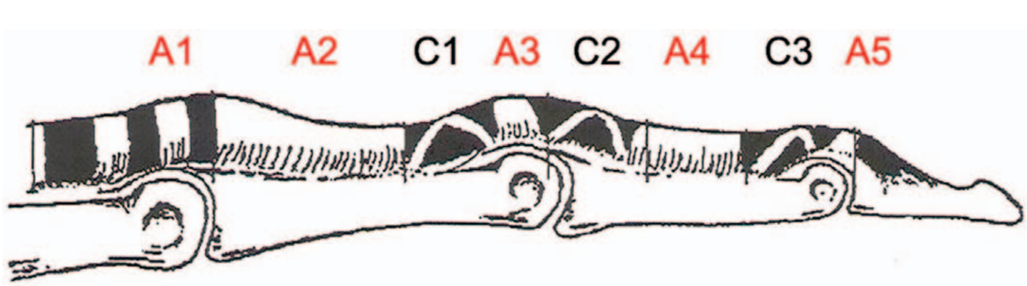

Fig. 4. Annular pulleys of the flexor tendon sheath. (Reprinted with permission from Lehfeldt M, Ray E, Sherman R. Treatment of flexor tendon laceration. *Plast Reconstr Surg*. 2008;121:1–12.)

laceration is in the digit, the vinculum may prevent retraction of the tendons. If the tendons have retracted, however, there are a number of techniques to bring the proximal tendon stump into the wound. The first is by "milking" the forearm from proximal toward the hand while also flexing the wrist, which may deliver the proximal tendon edge into the wound. If this is not successful, an atraumatic clamp may be placed blindly within the sheath proximally to grab the end of the tendon stump. If this is not successful, the incision should be extended proximally to retrieve the tendon. If the tendon is found proximal to the flexor sheath, it is fed back into the sheath with a pediatric feeding tube or tendon passer. Once the tendon edges have been brought into the wound, a 25-gauge needle may be placed transversely across the proximal stump through the sheath to prevent re-retraction (Fig. 5).

There are nuances to the operative approach of repair of a tendon laceration based on its location in the hand (zone I to zone V). Zone I injuries involve the flexor digitorum profundus tendon alone, and the attached vincula on the proximal stump often prevent proximal retraction of the tendon. In very distal lacerations, where repair is not possible, the tendon may be repaired by a Bunnell pullout suture over a button, or by placing a suture anchor into the distal phalanx.[24] In zone II, because of the close proximity of the flexor digitorum superficialis and flexor digitorum profundus tendons, the flexor digitorum profundus tendon traveling through the Camper chiasm, and the flexor sheath, adhesion formation between the two tendons is common. One way to reduce the risk of adhesion formation is by repairing only one slip of the flexor digitorum superficialis tendon, ensuring that there is adequate room within the chiasm during motion. This has been shown to decrease resistance and increase glide of the flexor digitorum superficialis and flexor digitorum profundus tendons.[25,26] Most surgeons, however, support repairing both the flexor digitorum superficialis and flexor digitorum profundus tendons in zone II injuries if possible without leading to impaired motion.[27–29]

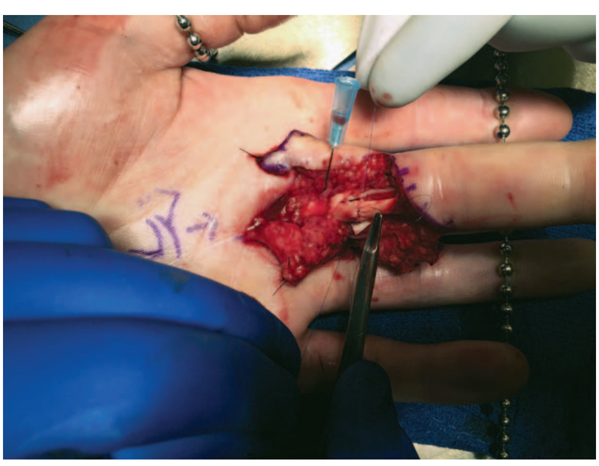

Fig. 5. A 25-gauge needle placed transversely across the proximal stump through the tendon sheath during repair.

Zone III and zone V tendon repairs have less risk of adhesion formation because of having improved vascularity and more space. Zone V injuries should be treated urgently because of the proximity of the neighboring neurovascular structures, and retraction of the tendons.

Zone IV repairs are uncommon because of the protection from the transverse carpal ligament. When these occur, they commonly occur with multiple tendon injuries and a concomitant median nerve injury.

Repair Techniques

The goal of flexor tendon repair surgery is to create a strong, stable repair that allows for smooth gliding of the tendon and early motion that prevents the formation of adhesions that will impair tendon gliding. Tendon repair occurs in three overlapping biological phases.[30] During the first few days is the inflammatory phase, where the tendon is infiltrated by red blood cells, white blood cells, platelets, growth factors, and cytokines/chemokines. A fibrin clot is formed, macrophages remove necrotic debris, and tenocytes are recruited to the wounded area and stimulated to proliferate.[31] The proliferative phase occurs after the first few days and is associated with increased synthetic activity and is directed by macrophages and tenocytes. Macrophages shift from being phagocytic to reparative and release cytokines/chemokines to direct cell recruitment.[32,33] One to 3 weeks after repair,[34] the construct is weakest and relies wholly on the suture and knots to prevent gap formation and failure. The remodeling phase begins at approximately 4 weeks, where collagen I synthesis increases, collagen III decreases, and the extracellular matrix aligns.[33] Scleraxis, tenomodulin, collagen I, and decorin are genes that can be associated with tendon differentiation.

Different types of suture materials have been studied in flexor tendon repair,[23,35] although no specific suture type has demonstrated definitive superiority. The suture material and caliber, the number of strands that span the repair, the location of the knot, and the use of locking and nonlocking techniques all affect the repair strength and overall outcome of repair.[36–38] Although the modified Kessler, four-strand core suture technique has been commonly used, several different techniques involving grasping, cruciate, mattress, cross-stitch, and locking configurations have been described and used in flexor tendon repair[38–40] (Figs. 3 and 6). Although the "ideal" repair continues to be studied, the strength of the repair is directly related to the number of strands that cross the repair.[41–46] Because of the number of variables in tendon repair surgery (e.g., suture caliber, suture material, type of repair), there has been a great deal of recent research aimed at elucidating the "ideal" tendon repair. Thurman et al. showed that six-strand repairs were stronger than four, and four-strand repairs were stronger than two.[47] These data, however, need to be reconciled with the fact that more suture strands crossing a repair site leads to more suture bulk and thereby increases the resistance to gliding of the tendon. Gelberman et al. have shown that gap formation of greater than 3 mm leads to an increased risk of rupture,[34] and they also showed that gap formation of greater than 3 mm increases susceptibly to rupture in both four- and eight-strand repairs.[48] Taras et al. found that 2-0 suture was 51 percent stronger than 3-0 suture, 3-0 suture was 52 percent stronger than 4-0 suture, and 4-0 suture was 66 percent stronger than 5-0 suture.[49] Hatanaka and Manske, however, showed that 2-0 suture was equivalent to 3-0 and 4-0 suture if a locking repair was used.[50] Osei et al. recently compared the tensile properties of a 3-0, four-strand flexor tendon repair with a 4-0, four-strand repair and a 4-0, eight-strand repair.[51] They concluded that although larger caliber suture has superior tensile properties, the number of core suture strands across a repair should be prioritized over suture caliber. Strickland compiled force-to-rupture data of two-, four-, and six-strand repairs during various passive and active tasks[23] (Fig. 7). His results suggest that a four-strand or greater repair will withstand active range of motion, thus allowing for immediate active range of motion. (**See Video, Supplemental Digital Content 1**, which shows an example of a surgical repair of flexor tendon laceration. This video is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/C216***.)

Tendon strength is maintained with early active motion more than in passive protocols.[34] Momose et al. showed that the gliding resistance of the tendon increases as the suture caliber increases, if braided sutures are used, and if knots are exposed.[52] Studies have also shown that the

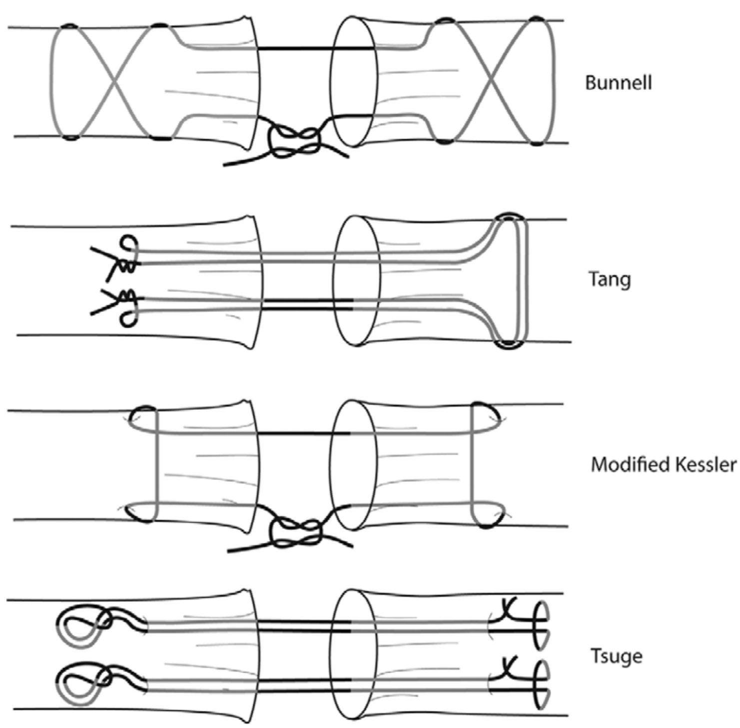

Fig. 6. Examples of core suture techniques. (Reprinted with permission from Farnebo S, Chang J. Practical management of tendon disorders in the hand. *Plast Reconstr Surg*. 2013;132:841–853.)

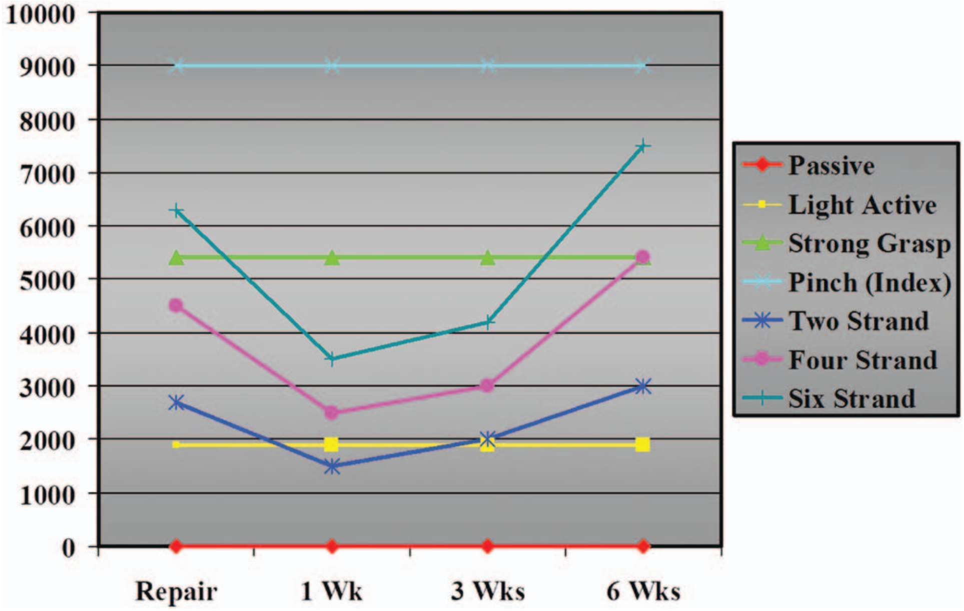

Fig. 7. The forces imparted onto a tendon repair generated by various activities relative to strand strengths. (Reprinted with permission from Neumeister MW, Amalfi A, Neumeister E. Evidence-based medicine: Flexor tendon repair. *Plast Reconstr Surg*. 2014;133:1222–1233.)

use of an epitendinous repair (typically with 6-0 monofilament suture) may add 10 to 50 percent increased strength to the tendon repair. Papandrea et al. described the epitendinous-first technique, which imparted a greater than 20 percent increase in strength compared with the modified Kessler technique alone.[53] This suture is typically placed into the epitenon approximately 2 mm from the tendon edges.[54] The strength of the repair does weaken by approximately 50 percent at 1 to 3 weeks in the unstressed tendon repair,[34] and has been shown to have increased tensile strength thereafter.[55]

Because of the heterogeneity of tendon injuries, and the lack of high-level clinical studies that compare repair techniques, there are currently no clinical practice guidelines or quality measures for flexor tendon repair. In an adult patient with a flexor tendon injury, we typically start with the epitendinous repair first with 6-0 monofilament suture. This aligns the tendon edges first and makes placing the core sutures easier. We then repair the

Video. Supplemental Digital Content 1, which shows an example of a surgical repair of flexor tendon laceration, is available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, at ***http://links.lww.com/PRS/C216***.

tendon with a four-strand core suture placed 7 to 10 mm from the tendon edge, as this has been shown to increase gap resistance and strength.[45,56–58]

REHABILITATION

The surgeon will vary postoperative rehabilitation after tendon repair based on the quality of the repair and tissue and the reliability of the patient to follow precautions. There are three general tendon repair rehabilitation protocols: complete immobilization, early active range of motion, and controlled passive range of motion only. All protocols use a dorsal blocking splint with the wrist in 30 degrees of flexion and metacarpophalangeal joints in 70 degrees of flexion. In general, complete immobilization of the repaired tendon is limited to children or adults that demonstrate unreliability in following postoperative precautions.[59] However, recent studies have suggested that children may be able to follow an early active protocol.[60–61] In noncompliant adults, or those that are unable to comprehend an early active protocol, passive range of motion may be used. In the Duran protocol, the extremity is kept splinted and the patient or therapist uses their uninvolved hand to passively range the finger to promote tendon gliding.[62]

The benefits of imparting early load to a repair site to tendon healing and gliding have been well established in the literature. Tendons that are mobilized are stronger than immobile tendons at 2 weeks after repair, and have been shown to have increased tensile strength, decreased adhesion formation, and improved tendon gliding.[55] Despite the biomechanical testing that has demonstrated the advantages of early active protocols to the traditional passive range-of-motion protocols, a previous Cochrane review was unable to conclude superiority of any specific protocol.[63] A subsequent randomized controlled trial showed superior range of motion and patient satisfaction in the active therapy group compared with the passive group.[64] Despite the active motion, this group did not have increased tendon rupture rates.

OUTCOMES

Despite the many advances in surgical technique in experimental models, most clinical outcomes are low level, with only a limited number of high-level efficacy studies to guide clinical care. A recent meta-analysis evaluated clinical outcomes of flexor tendon repair from 39 studies and analyzed repair zone of injury, core suture, use of epitendinous suture, and date of publication (before or after January 1, 2000).[65] The authors excluded articles if they did not report information on reoperation, rupture, or adhesions. Only one of the two randomized controlled trials was considered high quality; however, this study compared rehabilitation protocols and not surgical technique.[64] Twenty-seven of the observational studies were low quality and eight were high quality. The authors found that postoperative rupture rates are approximately 4 percent, and found no correlation with core suture technique and epitendinous suture use with rupture rates. Repairs using epitendinous sutures, however, had an 84 percent lower chance of reoperation than repairs without it. Adhesion rates were found to be 4 percent. Age, gender, zone of injury, use of an epitendinous suture, and date of publication, however, were not predictive of adhesion formation after flexor tendon repair. A more recent systematic review of two-strand versus multistrand core suture techniques was completed.[66] The authors found no difference between these repair techniques, but were unable to draw a definitive conclusion because of the variation in study designs and multiple variables.

CONCLUSIONS

Overall, there have been significant advances in the study of suture technique and rehabilitation protocols for flexor tendon lacerations that can be used to guide the operative surgeon. However, there is a need for high-level efficacy studies to evaluate whether results from experimental surgical studies and rehabilitation studies can be translated to clinical care.

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