Acute tendon injuries

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Abstract

Tendon injuries are common and can result in significant impairment of function. This review outlines key principles as well as specific treatments of injury to flexor and extensor tendons in each zone. Technical considerations for tendon repair and cautions are emphasized. New developments from research in the field of tendon repair are highlighted. Rehabilitation is not discussed as this is covered in another chapter.

Keywords acute; extensor; flexor; tendon; zone

Introduction

The topic of flexor and extensor injuries is large and impossible to discuss in detail in a single article. The aim of this review is to discuss acute tendon injuries in adults and provide a brief overview of treatment. Rehabilitation will not be discussed as it is dealt with in another article in this edition.

General management principles

A number of general[1] principles apply to both flexor and extensor tendon management:

- Obtain a thorough history including hand dominance, occupation and mechanism of injury[2]
- Meticulous examination assessing the patient for abnormal cadence, weakness, lack of function, wounds and neurovascular function. Perform radiographs to exclude bony injuries
- It is important to check tetanus immunity and manage appropriately
- Depending on the zone of injury and number of tendons involved, regional or general anaesthetic is preferable as a tourniquet will often be needed and incisions may be extended to locate the proximal stump. Create the best environment to give the best chance of a successful repair. Single finger and more distal injuries are amenable to wide awake surgery
- Perform a thorough debridement and washout of the wound, while attempting to maintain as much tendon length as possible. If there is any concern regarding the degree of contamination and an increased risk of infection, the repair can be performed as a staged procedure after the debridement

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- Use prophylactic antibiotics and adjust type, dose and duration of treatment according to the injury
- Extensile incisions will often be needed to retrieve tendon ends. Rather make longer incisions than causing more soft tissue trauma during surgery
- Minimize tendon handling as much as possible and use an atraumatic surgical technique. Attempt to only handle the cut end of the tendon minimally using a non-toothed forceps[3]

Flexor tendon injuries

Flexor tendon injuries have always been approached with caution, especially in zone I and II where poor outcomes and stiffness is often seen. It is important to note the close proximity of nerves in the forearm, wrist and hand. Flexor tendon injuries are often associated with nerve injuries and patients should be carefully examined to exclude this. Even if a nerve injury has been excluded by way of clinical examination, one should be prepared to perform a nerve repair when exploring flexor tendon injuries.

Anatomy

The long flexor tendons consist of the flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS) and flexor pollicis longus (FPL).

The tendons of FDS arise from their muscle belly in the distal third of the forearm and pass through the carpal tunnel with the middle (MF) and ring finger (RF) tendons superficial to the index (IF) and little finger (LF) tendons. The FDS tendons pass deep to the neurovascular structures in the palm and the FDS tendon of each finger remains superficial to the FDP tendon until it enters the flexor sheath and splits into two slips at the proximal level of the proximal phalanx and encircles the FDP tendon to insert at the base of the middle phalanx.[4]

The FDP tendons from the LF, RF and MF arise from a common muscle belly. The IF FDP tendon has its own muscle belly. The FDP tendons lie deep and ulnar to the FDS tendons in the forearm and pass deep to the FDS tendons through the carpal tunnel. They remain deep to FDS tendon to each finger until the FDS splits and then becomes superficial to the FDS and continuous as the only tendon beyond the FDS insertion to the middle phalanx until its own insertion into the base of the distal phalanx.[4] The lumbrical muscles originate from the FDP tendons distal to the carpal tunnel.

The FPL tendon arises from its muscle belly deep and radial in the forearm and runs along the radial border of the carpal tunnel and through the thenar muscles and through its own flexor sheath to the base of the distal phalanx.[4]

The flexor sheath is made up of five annular (A1, A2, A3, A4, A5) and three cruciate (C1, C2, C3) pulleys and extends from the base of the proximal phalanx to the distal phalanx (Figure 1). Within the sheath, tendons are covered by a thin layer of synovium.

The A1 pulley attaches to volar plate of the metacarpophalangeal joint (MCPJ), the A3 pulley to the volar plate of the proximal interphalangeal joint (PIPJ) and the A5 pulley to the volar plate of the distal interphalangeal joint (DIPJ). The A2 pulley attaches to the volar margin of the middle part of the
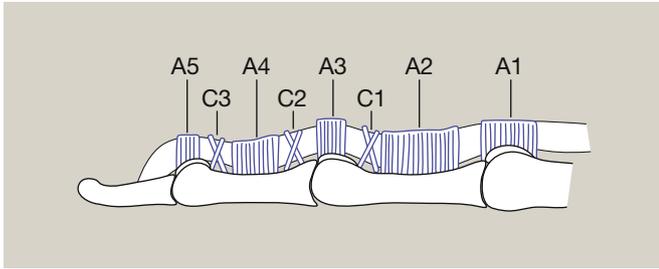
Figure 1 Pulleys of the flexor sheath.

proximal phalanx and the A4 pulley to the same area on the middle phalanx. The C1 pulley is just proximal to the A3 pulley and the C2 pulley just distal to it. The C3 pulley is just proximal to the A5 pulley. The annular pulleys are strong and designed to keep the tendons close to the bone to provide maximum mechanical advantage.[4]

The thumb has two annular and one oblique pulleys. The A1 pulley is volar to the MCPJ and the A2 pulley volar to the interphalangeal joint (IPJ) of the thumb. The oblique pulley runs across the volar surface of the proximal phalanx from proximal-ulnar to distal-radial.[4]

Short and long vinculae to both the FDS and FDP tendon provides a vascular supply to the tendons within the flexor sheath. Nutrition is also provided at the osseo-tendinous junction distal, the musculotendinous junction proximal, digital vessels and through synovial fluid diffusion.[4]

The wrist flexors are the flexor carpi radialis (FCR) and the flexor carpi ulnaris (FCU). Both pass superficial to the transverse carpal ligament. The FCR passes through a groove in the trapezium before inserting on the base of the second and third metacarpal base. The FCU encloses the pisiform, which acts as a sesamoid bone and inserts onto the base of the fifth metacarpal.[1]

Zones
Injuries are divided into five zones[4] (Figure 2).

Zone 1: from the FDP insertion to the FDS insertion and thus only involves the FDP tendon. Closed avulsion injuries in this zone has been classified by Leddy and Packer (Jersey Finger):

- Type I: Avulsion off the distal phalanx, without fracture, with rupture of all the vinculae and retraction into the palm.
  - Type II: Similar to type I, but the vinculae stay intact and the tendon only retracts to the PIPJ.
  - Type IIIA: Avulsion fracture with a large fragment, preventing retraction beyond the DIPJ.
  - Type IIIB: Similar to IIIA, but associated with avulsion of the FDP tendon off the bony fragment.
  - Type IV: Complex intra-articular fracture of the base of the distal phalanx.

Zone 2 (No man's land): from the FDS insertion to the proximal end of the A1 pulley or the distal extent of the lumbrical muscle. Essentially inside the flexor sheath where FDS and FDP run together. Zone 2 has been further sub-divided:[5]
- Zone 2A: Under the A4 pulley
- Zone 2B: Under the C1 pulley
- Zone 2C: Under the A2 pulley
- Zone 2D: Under the A1 pulley

Isolated pulley injuries can occur and is usually seen in rock climbers. It is mostly the A2 pulley that ruptures and the diagnosis can be confirmed with ultrasound or MRI.[6]

Zone 3: from the proximal edge of the A1 pulley to the distal edge of the carpal tunnel. Also, the area where the lumbrical muscle is attached to the FDP tendon.

Zone 4: within the carpal tunnel. Be aware of the close proximity of the median nerve which is superficial in the carpal tunnel.

Zone 5: from the proximal edge of the carpal tunnel to the musculotendinous junction. FPL ruptures can occur in this zone following volar plating of the distal radius.[7]

Repair techniques
It is not possible to describe every suture technique and knot (Figure 3), but there are a few general principles:[4]
- Minimize tendon handling as much as possible
- Repair the tendon anatomically without gapping or bunching and avoid malrotation of the tendon
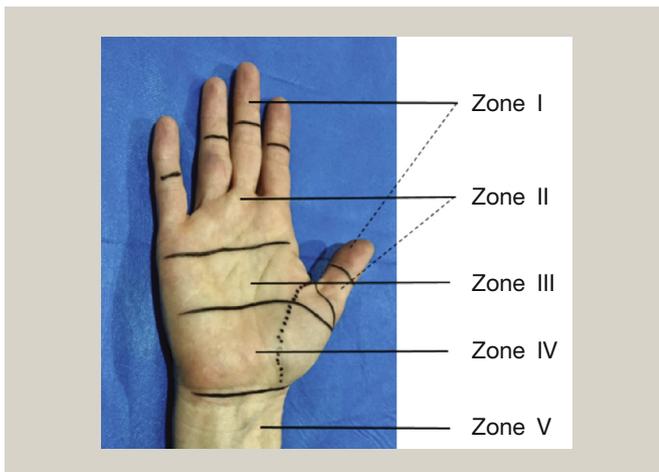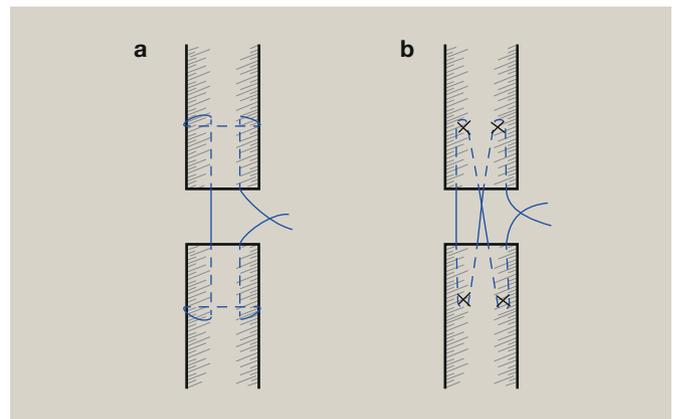

Figure 2 Flexor tendon zones.

Figure 3 (a) Modified Kessler technique. **(b)** Adelaide suture, with modification in knot position from the original Adelaide suture (four-stranded locked cruciate).

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- Increased number of strands crossing the repair is stronger, but may lead to increased bulk and more resistance to tendon gliding. A 3-0 or 4-0 non-absorbable suture can be used depending on the size of the tendon. Aim for a minimum of four crossing strands, especially in Zone I — III. The knot is a weak point and a single knot is stronger.[8,9] In vitro studies suggest that it is better to place the knot outside the tendon, but has not been shown in in vivo studies.[9] An outside knot will also lead to more resistance
- The length of purchase of the core suture within the tendon should be between 7 mm and 10mm[9,10]
- A locking core suture technique will lead to a stronger repair when compared to a grasping suture[8]
- Epitendinous sutures, using a 6-0 non-absorbable suture, should aim to create a smooth repair and can add up to 30% strength to the tendon repair. A purchase of at least 2 mm on each side should be achieved[11]
- Achieve a strong enough repair to allow early active rehabilitation[8]
- The ideal suture material should have a high tensile strength, handle easily and cause very little tissue reaction[9]
- In partial injuries the tendon repair should be performed as per the usual technique if less than 60% of the tendon is intact. If more than 60% is still intact, a repair is not required, but a debridement should be performed, especially in zone 1 and 2 to prevent triggering.[12]

The most important factor in tendon repair is a team approach. Good strong repair should be followed by a structured rehabilitation protocol, which should be spearheaded by the local hand therapist. A strong repair will allow an early active protocol, which will lead to better outcomes.[13] It is however just as important for the patient to understand the injury, the treatment and the rehabilitation protocol and to actively participate.

The timing of the repair is debatable. Aim to perform the repair as soon as possible and be prepared to perform reconstructive surgery if there is a considerable delay from time of injury. A primary repair can usually be performed with 7–14 days,[3] but better results are achieved if performed within 7 days.[14] A more important factor is that the repair is performed by an experienced surgeon.[10]

Management
The diagnosis is usually a clinical diagnosis. Open injuries with a suspected injury warrants exploration. In closed ruptures ultrasound can be used to confirm the diagnosis.[15]

Zone 1: Type I and II injuries can be repaired using either a suture anchor or a traditional pull-out suture tied over a button on top of the nail plate.[4]

Type IIIA injuries depend on the size of the fracture fragment. A large fragment can be treated with open reduction and internal fixation, whereas a small fragment can be treated with a soft tissue repair as in a type I or II injury.[4]

A type IIIB and type IV injury needs to be treated as both a bony and soft tissue injury, which is often very challenging.[4]

A cadaver-based study compared an all inside technique (with the sutures tied over the distal phalanx) to the traditional pull-out suture and two different suture anchors. They found no difference in terms of tensile stiffness, ultimate load and work to

failure.[16] In a retrospective cohort they found no significant clinical difference at 1 year follow-up between the pull-out suture technique and suture anchors, but they found a significant improvement in time to return to work in the suture anchor group.[17] A further cadaver study found a Corkscrew anchor biomechanically superior to a Micro-Mitek anchor, but stated that is most likely due to the Firewire suture used in the Corkscrew anchor versus Orthocord in the Micro-Mitek anchor as there was no difference between the anchors in terms of pull out from the bone.[18]

Management of open zone 1 injuries depend on the length of the distal stump. If the distal stump is 1 cm or longer, a primary repair can be done using a non-absorbable 3-0 or 4-0 four-stranded core suture and epitendinous suture. If the stump is shorter than 1 cm, the repair should be performed using a pull-out suture tied over a button or a suture anchor.

Zone 2: a good history may be helpful. If an open injury occurred with the fingers in a flexed position, the distal stump is likely to be much more distal then the laceration. If the finger was in an extended position it is likely that the distal stump will be very close to the skin laceration.[2,19] A laceration in what looks like zone 3, could essentially be a zone 2 injury if the fingers were flexed at the time of injury.

During exposure it is important to avoid longitudinal incision crossing over skin creases. It is better to use either a Brunner-type incision, mid-axial incision or a combination of the two.[4] The proximal end often retracts into the palm. Attempt to milk it into the zone of injury (flex the wrist and the fingers and massage over the tendon from proximal to distal), but avoid blindly grasping up the tendon sheath to grab it. If unable to milk it into the zone of injury, it is better to make a second incision proximal[10] to the A1 pulley, where the proximal end will usually be. It can then gently be fed into the sheath or pulled through by suturing it to a feeding tube. The proximal stump can be held in position by placing a small needle (25-gauge) through an intact pulley and into the tendon.[3] The distal stump can by delivered into the zone of injury by flexing the finger.[3]

The tendon should be repaired using a 3-0 or 4-0 non-absorbable 4-stranded core suture with an epitendinous suture. Single knot core sutures are biomechanically stronger than a double-knot technique.[10] Tension the suture material before starting and make sure to tension the repair correctly. Avoid gapping as it decreases repair strength, but avoid bunching as this will increase resistance to tendon gliding. Some controversy exists as to whether FDP and FDS should be repaired. Some surgeons will only repair FDP, while others will repair only a single slip of the FDS tendon and use the other slip to reconstruct the pulley.[3] It may be wise to first repair the FDP and then to assess how much gliding resistance is present before deciding whether to repair the FDS or not. The FDS repair technique will depend on the location of the injury and the flat slips can repaired with a modified Kessler suture (two-stranded) and will essentially be a four-stranded repair if both slips are repaired. Where the FDS is a single tendon, a modified Kessler suture can still be used (two-stranded) with an epitendinous circumferential suture.

The general teaching is to preserve the A2 and A4 pulleys, and that the other pulleys can be sacrificed as necessary.[4] If the

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original injury has left the sheath and pulley system mostly intact, try and preserve as much of it as possible and create an adequate window in the pulleys to repair the tendon and provide free gliding of the tendon. It may sometimes be necessary to partially excise either the A2 or A4 to achieve this, but care should be taken to leave as much of it as possible.[19] Stiffness rather than bow stringing is generally a much bigger problem in zone 2.

If the pulleys have been extensively damaged, it may be necessary to reconstruct the pulley. A cadaver study looked at the effect of reconstructing the A2 pulley by wrapping a single loop of palmaris longus around the phalanx. They compared this to an uninjured tendon with intact sheath and a zone 2 repair with an intact A2 pulley. They found that pulley reconstruction decreased gliding resistance, but caused an increase in bow-stringing without affecting maximum flexion angle.[20]

A cadaver-based study looking at different number of 'figure of 8' core sutures found the lowest friction and highest tensile strength when using two 'figure of 8' core sutures (four-stranded) of 4-0 Firewire with a 6-0 Prolene epitendinous suture. They also showed a 62% increase in friction when repairing the FDS as well, but this was not significant (p = 0.06).[21]

A biomechanical study using sheep tendons showed similar strength as long as the total suture volume across the repair stayed constant, by increasing the suture calibre while decreasing the number of strands crossing the repair site. They showed significant increase in repair strength by adding epitendinous sutures.[22] Not all studies confirm their findings regarding core sutures. A different cadaver study showed that it is better to use more strands across the repair site than to use an increased suture calibre.[23]

A biomechanical study looking at epitendinous sutures (Figure 4) in isolation did not find a significant biomechanical advantage in locking, grasping or embedding of sutures, but placement of the sutures at 5 mm rather than 2 mm from the repair site provided higher biomechanical strength.[24]

Outcomes of tendon repairs in zone 2 has been rated as fair or poor in 7−20% of cases, including complications such as adhesion formation with stiffness, contractures, tendon rupture, triggering, pulley failure and bowstringing, quadrigia, swan neck deformities and lumbrical plus deformities.[20]
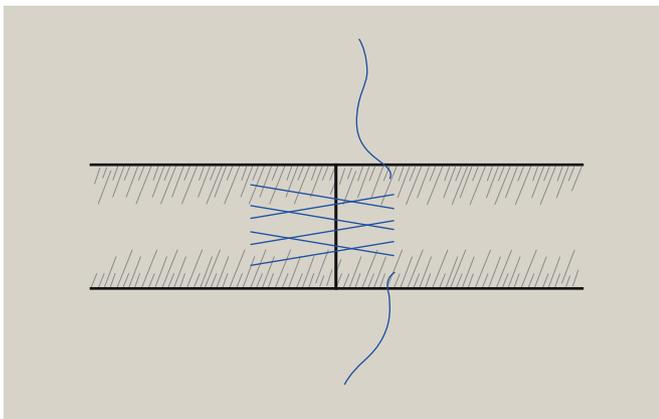
Isolated pulley ruptures or sprains can be managed conservatively with splinting. Multiple ruptures should be managed surgically with a pulley reconstruction.[6]

An online survey involving 410 hand surgeons in the USA was performed to determine common trends in the repair of zone 2 flexor tendon injuries. A summary of their results can be found in Table 1.[25]

Zone 3: repairs in zone 3 are more forgiving than zone 2.[26] Depending on the location, the transverse carpal ligament (proximal injuries) or the A1 pulley (distal injuries) may need to be released. A four-stranded repair with epitendinous suture should be performed. The FDS and FDP must be repaired. Carefully examine the common digital nerves. If multiple tendons have been injured and a long surgical time expected, it is acceptable to omit the epitendinous repair and some surgeons routinely omit it.[27] The lumbrical muscle should not be repaired.

Predictors of improved outcomes in zones 1 to 3 are non-smokers, stronger repairs, repair of the FDS, limited release of the pulley system as required and early active protocols.[28]

Zone 4: injuries in zone 4 are rare. The transverse carpal ligament needs to be divided. Due to the superficial nature of the median nerve it is likely to be injured. Proximal extension is necessary to locate the proximal ends of the tendon which would have retracted into the forearm. A four-stranded technique should be used for the repair using a 3-0 non-absorbable suture without an epitendinous suture.[27] Some authors will not repair the FDS if there has been multiple tendons injured, due to the confined space in the carpal tunnel.[19] A good knowledge of anatomy is essential to match the tendons correctly.

Figure 4 Short segment showing Silfverskiöld epitendinous suture technique.

Summary of preferences of hand surgeons in the USA[25]

Technique	
Modified Kessler	42.3%
4-stranded cruciate	26.1%
Strands	
2-strands	5.8%
4-strands	65.3%
6-strands	17.5%
Epitendinous	
Yes	96.7%
Flexor sheath repair	
No	79.4%
Partial release A2/A4 pulley	
Yes	89%
FDP vs FDS	
FDP only	8.1%
FDP and FDS	65.2%
FDP and single slip FDS	26.7%
Material	
Fibrewire	29.8%
Ethibond	24.4%
Size	
3−0	51.5%
4−0	46.7%

Table 1

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Zone 5: injuries in zone 5 can vary widely in terms of the severity of the injury. It can be a superficial injury involving only one or two of the wrist flexors or major injury involving arteries and nerves as well as multiple (if not all) of the flexor tendons. The suture technique is the same as for zone 4. When all the tendons, nerves and arteries have been injured a simple two-stranded modified Kessler technique can be used to repair the tendons. The proximal stumps can retract into the muscle bellies and can be difficult to locate. A good knowledge of anatomy is essential to match the tendons correctly.

Repair of the FPL: the thumb flexor tendon must be repaired using the same principles as for the other fingers. The FPL always retracts and will often be found in the thenar muscles or even in the carpal tunnel or even more proximal. Be prepared to make a more proximal incision to locate it. The oblique pulley should be preserved as far as possible.

Extensor tendon injuries

Injuries to the extensor tendons are more common than the flexor tendons and often seen as less complex with better outcomes. Even though it is not as often associated with nerve injuries, the surrounding soft tissue injuries with loss of cover and loss of tendon can be more severe. The management of distal injuries can be challenging with poorer outcomes if not managed with care.

Anatomy

Extensor function is controlled by an intrinsic and extrinsic system. These function as an intricately linked system. The extrinsic tendons can be divided into three groups: Wrist extensors, finger extensors and thumb extensors. The wrist extensors are extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB) and the extensor carpi ulnaris (ECU). The finger extensors are extensor digitorum communis (EDC), extensor indices proprius (EIP) and extensor digiti minimi (EDM). The thumb extensors are abductor pollicis longus (APL), extensor pollicis brevis (EPB) and extensor pollicis longus (EPL). ECRL is supplied by the radial nerve and the other muscles by the posterior interosseous nerve.[29] The extrinsic tendons pass through six synovial lined tunnels (Figure 5) underneath the extensor retinaculum. On the dorsum of the hand the EDC tendons of the fingers are connected to each other through the junctura tendinum. At the MCPJ the EDC
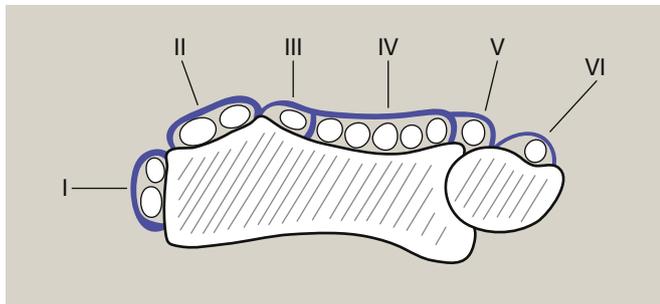
flattens and forms the dorsal hood which is attached to the volar plate through two sagittal bands, which is responsible for the extension at the MCPJ. This also limits the excursion of the EDC as it anchors it to the volar plate. The EIP provides additional extension to the IF, while the EDM does the same for the LF. Both of these attach to the dorsal hood, ulnar to the respective EDC attachments. The extensor apparatus of the finger divides into a central slip and lateral bands distal to the MCPJ. The central slip inserts onto the base of the middle phalanx and extends the PIPJ. The two lateral bands continue along the digit and join each other on the dorsum of the middle phalanx to form a single tendon which inserts on the base of the distal phalanx and extends the DIPJ.

The intrinsic system consists of the interossei (palmar and dorsal) and the lumbricals. They pass volar to the joint axis of the MCPJ and attach onto the lateral bands on each side of the fingers, except the ulnar side of the LF. Interconnections are present between the central slip and the lateral bands, which allows the force of pull of the intrinsic muscles to lie dorsal to the joint axis of the PIPJ and the DIPJ. The intrinsic muscles are therefore responsible for flexion at the MCPJ and extension at the PIPJ and DIPJ.

In the thumb the EPL extends the interphalangeal joint (IPJ), EPB the MCPJ and the APL the carpometacarpal joint (CMCJ). The EPB and EPL are attached to a dorsal hood over the MCPJ, which can lead to difficulty in assessing injuries as the EPB can contribute to extension at the IPJ. The intrinsic muscles of the thumb will contribute to flexion at the MCPJ and extension at the IPJ.[30]

Zones

As a general rule the uneven numbered zones are located over joints and the even numbered zones over bones[29] (Figure 6).

Zone I: these are known as mallet finger injuries and is an injury to the extensor apparatus at the level of the DIPJ. Most commonly a closed injury caused by forced sudden flexion at the DIPJ causing avulsion of the tendon, but can also be caused by forced hyperextension with axial compression as well as lacerations. It can be subdivided into four types (Doyle):[30]
- Type 1: Closed hyperflexion injury with or without a small avulsion fracture
- Type 2: Laceration
- Type 3: Deep abrasion
- Type 4A: Transepiphyseal plate fracture

Figure 5 Extensor compartments containing abductor pollicis longus and extensor pollicis brevis in I, extensor carpi radialis brevis and extensor carpi radialis longus in II, extensor pollicis longus in III, extensor digitorum communis and extensor indices proprius in IV, extensor digiti minimi in V and extensor carpi ulnaris in VI.
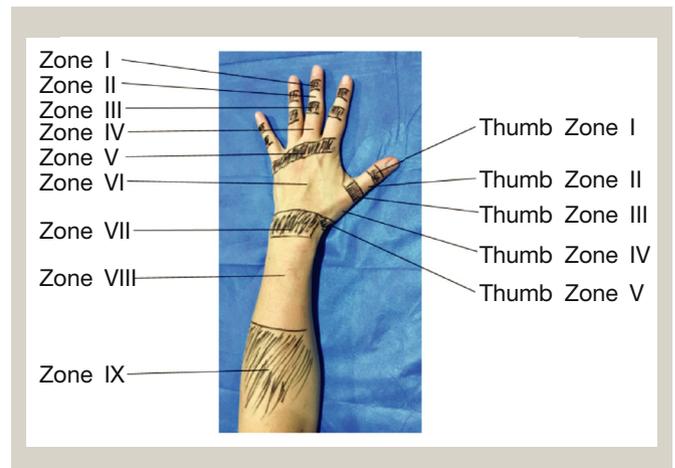

Figure 6 Extensor tendon zones.

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- Type 4B: Hyperflexion injuries with fracture involvement of 20–50% of the articular surface
- Type 4C: Hyperextension injury with fracture involvement of >50% of the articular surface.

The distal phalanx will be held in a flexed position with an inability to actively extend at the DIPJ.

Zone II: the area over the dorsum of the middle phalanx. Mostly open injuries.

Zone III: injury of the central slip over the PIPJ, which can lead to a classic boutonnière deformity. These injuries can be open or closed injuries. It is important to always look for a central slip injury in a volar PIPJ dislocation.

Patients with an injury to the volar plate or collateral ligaments (jammed finger) will often present with the PIPJ in a flexed position. It is very important to differentiate between this and a true central slip injury, as these injuries are better treated with early mobilisation as treating it as a central slip injury can lead to a very stiff finger. Elson's test can be used to clinically test if the central slip is intact.

Zone IV: the area of the extensor apparatus over the proximal phalanx. Injuries are mostly caused by lacerations.

Zone V: the area of the extensor apparatus over the MCPJ, including the dorsal hood and sagittal bands. Closed sagittal band injuries have been classified my Rayan and Murray:[31]
- Type 1: Injury without instability
- Type 2: Injury with subluxation of the extensor tendon
- Type 3: Injury with dislocation of the extensor tendon

Zone VI: the area on the dorsum of the hand between the MCP and the extensor retinaculum. Even though it is rare, ECRB and ECRL avulsion injuries can occur as closed injuries in Zone VI. The mechanism of injury is rapid acceleration-deceleration, such as seen in boxers for instance. In the correct setting this injury should be considered, especially if a fracture is noted at the base of the second or third metacarpal.[32]

Zone VII: this zone corresponds to the extensor retinaculum. Tendons in this zone, especially extensor pollicis longus (EPL) is vulnerable in closed wrist injuries as well. EPL rupture is a well known complication of wrist fractures, even without operative intervention. In a cadaver study it was noted that the musculotendinous junction of EPL is located underneath the extensor retinaculum in 90% of cases. The musculotendinous junction is a relatively hypo-vascular area and the EPL extensor tunnel is tight compared to the other extensors. The authors hypothesize that any wrist trauma effectively causes a compartment syndrome at the musculotendinous junction leading to muscle necrosis and tendon rupture.[33]

This is also the zone where tendon ruptures occur in rheumatoid patients (Vaughn Jackson syndrome).

Zone VIII: Zone VIII is the area of the forearm from the proximal edge of the extensor retinaculum to the musculotendinous junctions.

Zone IX: this zone corresponds to the muscle bellies in the proximal forearm. The most important aspect of injuries in this zone is to differentiate between an isolated muscle injury and an injury to the posterior interosseous nerve (PIN).

Thumb: the thumb is divided in five separate zones: zone I over the IPJ (EPL), zone II over the proximal phalanx (EPL), zone three over the MCPJ (EPL and EPB), zone IV over the metacarpal (EPL and EPB) and zone V over the CMCJ (EPL, EPB and APL). Distal to the MCPJ, the tendons do not tend to retract, but proximal to the MCPJ, the tendons will retract very far proximal and the surgeon should be prepared to extend the incision far proximal to locate the proximal ends.

Repair techniques

In zone I to zone V the tendons are generally flat. Multiple suture techniques have been described, but a figure-of-8, running interlocking horizontal mattress suture or a Silfverskiöld suture can be used.[34]

More proximal the tendons are more oval and therefore a core suture can be used. A modified Kessler core suture should be sufficient. It is also suggested by some authors to include an epitendinous suture.[30,34] Zone VI is the transition zone and may be flatter distally and more oval proximal. The suture technique can be adjusted according to the size and shape of the tendon in zone VI.

Non-absorbable sutures are preferable and the size of the suture will depend on the size of the tendon. Ranging from 5-0 distally (zone I-III) to a 3-0 or even 2-0 proximal.

Partial injuries do not need to be repaired as long as more than 50% of the tendon is intact.[35]

Management

The general posture of the hand must be observed as this can be an indication of tendon injury. The patient should be carefully examined for active extension, resisted extension, soft tissue loss and nerve injuries. It is important to obtain radiographs to exclude fractures.

Closed injuries should be carefully examined and if in doubt, an ultrasound[15,36] may be useful to further investigate. Any suspicion of extensor tendon injury in the face of an open wound warrants exploration in theatre. Injuries with extensive soft tissue loss and loss of tendons will initially require a thorough debridement and multiple surgeries including tendon transfers or grafting as well as soft tissue flaps. Even in the absence of tissue loss, it may be necessary to manage tendon injuries as a staged procedure with a debridement initially followed by a repair at a later date. This approach should be utilised in cases of severe contamination or concern regarding infection.

Zone I: if left untreated, zone I injuries will lead to in inability to extend the DIPJ and may eventually cause a swan neck deformity.[34]
- Type 1: Treat with splinting.[34] Wear the splint continuously for 6–8 weeks, followed by another 6–8 weeks of night splinting. Occasionally it may be necessary to place a trans-articular K-wire.
- Type 2: Open injuries should be treated with open repair using a figure-of-8 suture and a trans-articular k-wire

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across the DIPJ for 3 weeks followed by splinting for another 3 weeks. Alternatively, it can be splinted for 6 weeks following repair.

- Type 3: These injuries will require debridement with soft tissue reconstruction,[34] often as a staged procedure.
- Type 4A: Can be treated with closed reduction and splinting.[34]
- Type 4B and 4C: The size of the fragment is quoted as being the differentiating factor between type 4B and 4C. It is however the mechanism of injury and the congruency of the joint that plays a far more important role. The hyperextension injury will usually cause a fracture dislocation of the DIPJ. These cases have to be managed operatively with an open reduction internal fixation (ORIF) and interosseous wire loop or dorsal blocking splint and trans-articular k-wire.[34] A recent case series has shown good results with an intra-osseous suture technique with a trans-articular k-wire across the DIPJ without using a dorsal blocking wire.[37] In the classic type 4B (Flexion injury) the DIPJ should remain congruent. Therefore, if the DIPJ remains reduced, it can be managed with splinting as for a type 1, but it is important to repeat the X-rays in the splint and confirm congruency of the joint.

Zone I injuries of the thumb can generally be treated in a similar fashion as the other fingers.[34,38]

Zone II: injuries in zone II will usually be open injuries and if any doubt exists it should be explored. If more than 50% of the tendon is intact, without extensor lag, it can be treated with a short course of splinting. Otherwise a surgical repair with a figure-of-8 suture (or any appropriate suture as discussed earlier) with k-wire stabilization of the DIPJ should be performed. The wire can be removed at 3 weeks, but the DIPJ should be splinted in extension for a further 3 weeks. Active range of motion (ROM) of the MCPJ and PIPJ should be encouraged right from the start of treatment.[34]

Zone II thumb injuries are treated in a similar fashion.[38]

Zone III: open injuries in zone III should be managed with an open repair of the tendon. Any of the techniques discussed previously can be used. If the laceration has occurred at the insertion of the tendon, it may be necessary to use a suture anchor. The PIPJ should be stabilised and this can be done with a temporary k-wire across the joint.[34] The repair should be protected for a total of 6 weeks.

Closed injuries can generally be managed by splinting. The PIPJ should be splinted in full extension for 6 weeks, leaving the DIPJ free. This should be followed by another 6 weeks of night splinting. Indications for open repair in closed injuries are:[34]

- Displaced avulsion fractures of the base of the middle phalanx
- Instability of the PIPJ associated with loss of extension at the PIPJ
- Failure of non-operative management

Zone III lacerations of the thumb may include either EPL, EPB or both. The tendons should be repaired using a modified Kessler technique (on either side) and augmented by a Silfverskiöld-type suture dorsally. The MCPJ capsule should be repaired separately.

The thumb MCP and IPJ should be splinted in full extension for four weeks. An isolated EPB injury does not have to be repaired, but if noted during surgical exploration it is advisable to repair it.[38]

Zone IV: the mechanism of injury is usually a laceration and these injuries can be treated in a similar fashion as zone II injuries, except that the PIPJ should be immobilized for about 6 weeks.[34]

Thumb injuries can be treated in a similar fashion. The tendons are larger than in the fingers and the suture technique will be similar to the zone III technique for the thumb.

Zone V: open injuries should be treated with an open repair using one of the techniques mentioned earlier. The repair should be protected in a volar slab with the wrist in 30° of extension and the MCPJ in full extension. The PIPJ can be left free to allow active flexion. The repair should be protected for 3 weeks.

The 'fight bite' injury deserves special mention. All wounds in this zone should be surgically debrided and the MCPJ thoroughly washed out, because of the risk of joint inoculation. Microscopy samples should be taken and the patient treated with antibiotics. Septic arthritis of the MCPJ is a much greater issue here than the tendon injury.[34] If a tendon repair is required, this can be done as a staged procedure following the debridement.

Type 1 and 2 sagittal band injuries can usually be managed conservatively with splinting. Type 3 injuries in the athlete must be managed surgically with a repair. Patients who fail conservative management must also be managed surgically but will usually require a reconstruction.[39]

Zone V thumb lacerations can injure all three extrinsic tendons of the thumb. The tendons should be repaired as described for zone III and IV injuries.

Zone VI: open injuries are more common in this area and can be associated with extensive tissue loss. Loss of extension may not be as obvious due to the juncturae tendinum. EIP and EDM should be tested individually by asking the patient to extend the LF and IF MCPJ while keeping the MF and RF completely flexed. If an isolated EIP or EDM injury is suspected, possible surgical repair should be discussed with the patient, as they may have no functional loss. The more proximal the injury, the more oval the tendon becomes and therefore the suture technique may vary as discussed earlier. A modified Kessler should be sufficient.[38]

ECRB and ECRL avulsion should be treated with ORIF, if the fracture is large enough to allow this, or with suture anchors.

Zone VII: the tendons run inside the tunnels underneath the retinaculum. Acute injuries are caused by lacerations. Significant retraction of tendons can occur and it may be necessary to extend the incision proximal to locate the proximal ends. Tendons should be repaired using a cores suture (four stranded) with an epitendinous suture technique.[34,38] This is a difficult zone as the retinaculum tends to get in the way. Removal of the retinaculum may cause bowstringing. If at all possible, create a window in the retinaculum to allow repair and friction free glide of the tendon repair, without removing the whole retinaculum.[38] Otherwise the retinaculum can be opened in a step-cut fashion and repaired

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loosely over the tendon repair.[29,38] The repair should be protected for 3–4 weeks up to the PIPJ.

Closed EPL ruptures are treated with a EIP to EPL tendon transfer.[34,38]

Zone VIII: lacerations are the usual reason for injuries in zone VIII. These can be pure tendinous injuries, but the proximal ends of the tendons will retract into the muscle bellies and can be very difficult to find. If located, a modified Kessler or figure-of-8 suture can be used. If the injury occurs at the musculotendinous junction the tendons can be sutured to fibrous muscle septae using a figure-of-8 suture.[34] If multiple tendons are injured it can be very difficult to determine which tendons have been injured and which muscle bellies they should be sutured to. The goal is to maintain independent wrist and thumb extension.[34] Some surgeons will opt for a primary side-to-side tendon transfer.[38]

Zone IX: Zone IX is the muscle bellies and is usually caused by lacerations. Some surgeons repair the muscle bellies with figure-of-8 sutures,[38] but sutures often tear through the muscle bellies and therefore some surgeons perform an epimysial repair.

It is possible to treat even open zone IX injuries without repair (the skin wound should obviously be sutured). The patients should be placed in a splint with the wrist and MCPJs in full extension for 4 weeks, but keeping the PIPJ's free.

The most important aspect of managing injuries in zone IX, is whether the PIN has been injured or not. If there is even the slightest concern about whether the PIN has been injured, it should be explored.

Complications

Adhesion formation and stiffness is the biggest problem. Extensor lag can often be tolerated, but the lack of flexion with resultant loss of grip strength is a much bigger concern. Rupture of the repair, if detected early, can be managed a revision repair, otherwise secondary reconstruction is necessary. Boutonnière and swan neck deformities my also occur.[34]

Author's preferred repair technique

Flexor tendons

In zone 1 avulsions we would use either anchors or a pull-out suture technique. For tendon repairs we use an Adelaide core suture (4-stranded) 3-0 Prolene, with a 6-0 Silfverskiöld epitendinous suture in zone 1 and zone 2. In zone 3 to zone 5 we omit the epitendinous suture. In cases of multiple tendon injuries in zone 5, we use a modified Kessler suture.

In Zone 2 we always attempt to repair FDP and FDS and will cut a window in the pulleys for the repair and to allow smooth gliding.

Extensor tendons

In the flat distal tendons, we use multiple figure-of-8 sutures. We would immobilize the DIPJ and PIPJ, where indicated, with a trans-articular k-wire for 3 weeks, followed by 3 weeks of splinting. In the proximal injuries we use a Silfverskiöld epitendinous suture for the smaller tendons and an Adelaide suture for the larger tendons. In zone VII we will include an epitendinous suture.

Conclusion

To treat tendon injuries successfully a thorough knowledge of anatomy is essential. Injuries should be recognised early and one should always actively be looking to exclude tendon injuries. Have a low threshold for exploration in open injuries. Surgical repair should be performed by an experienced surgeon and should be performed in a hospital with a dedicated hand therapist who must actively be involved in the post-operative follow up and rehabilitation. A good repair without good rehabilitation is useless. ◆

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