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REVIEW ARTICLE

Diagnosis and treatment of flexor tendon injuries of the hand: what the radiologist needs to know

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Abstract
This article reviews the diagnosis and treatment of flexor tendon injuries of the hand highlighting flexor tendon anatomy, important pre-operative imaging findings, surgical options, and post-operative complications. Imaging plays a key role in guiding treatment of these difficult to manage injuries. Thus, it is important for radiologists to have a sound understanding of factors important in treatment decision-making. In the pre-operative setting, accurately identifying the location of the torn proximal tendon stump in subacute and chronic injuries helps dictate whether the patient is a candidate for a primary flexor tendon repair or may require a tendon reconstruction to restore function. In the post-operative setting, the status of the repair and presence of surrounding adhesions help dictate if and when the patient will require subsequent surgery and whether that surgery will be a tenolysis, revision repair, reconstruction, or fusion.

Keywords Flexor tendon tear · MRI · Ultrasound · Finger

Introduction

Flexor tendon injuries of the hand are relatively uncommon and challenging to manage for upper extremity surgeons. The incidence of flexor tendon injuries is about 7/100,000 person-years with injuries occurring more often in men and in younger patients [1, 2]. As injuries more commonly occur in the working age and younger population, they can lead to significant morbidity and limited function if not properly addressed. Imaging can help delineate the extent of injury in these cases, identifying important findings relevant to the treating surgeon, and can also identify complications of interventions. Thus, it is important for radiologists to understand the anatomy of the flexor tendons, including that of the flexor tendon sheath, as well as the classification and treatment of flexor tendon injuries. This will allow radiologists to provide useful information to the treating surgeons and help guide management to facilitate optimal outcomes for these difficult to manage injuries.

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Anatomy

The flexor digitorum superficialis (FDS) muscle originates at the medial humeral epicondyle as part of the common flexor tendon. The flexor digitorum profundus (FDP) muscle has a complex origin involving the proximal ulna distal to the common flexor tendon. Both muscles travel through the forearm in the volar compartments and terminate in four tendons, one supplying the index, long, ring, and small fingers respectively. The FDP and FDS tendons travel through the carpal tunnel and the palm before entering their respective flexor tendon sheaths at the proximal aspect of the metacarpophalangeal joint.

At the level of the metacarpophalangeal joint, the FDS tendon is positioned volar to the FDP tendon. Just distal to the metacarpophalangeal joint, the FDS tendon bifurcates and the FDP tendon passes between then volar to the FDS tendon slips at the level of the proximal phalanx (Fig. 1, Fig. 2). The

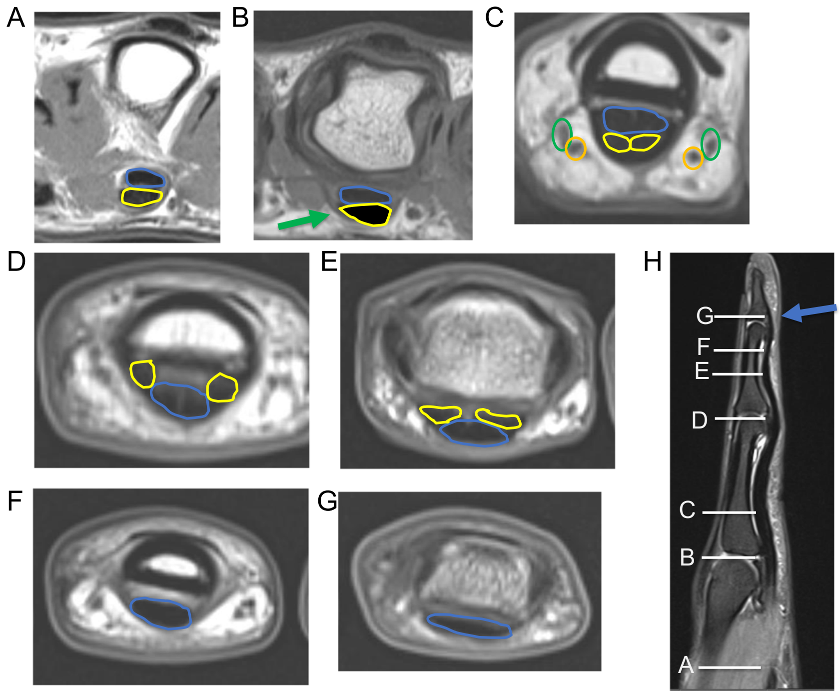

Fig. 1 Flexor tendon anatomy on MRI. **A**–**G** Axial T1 images at the level of the palm (**A**), A1 pulley (green arrow, **B**), proximal phalanx (**C**), proximal interphalangeal joint (**D**), mid portion of middle phalanx (**E**), distal portion of middle phalanx (**F**), and base of distal phalanx (**G**) demonstrate anatomy of the flexor tendons. At the level of the palm and A1 pulley (**A**, **B**), the flexor digitorum superficialis (FDS) tendon (yellow) is one tendon and superficial to the flexor digitorum profundus (FDP) tendon (blue). At the level of the proximal phalanx (**C**), the FDS tendon bifurcates and the FDP is positioned volar to the FDS tendon slips by the level of the proximal interphalangeal joint (**D**). The FDS tendon slips insert at the level of the middle phalanx (**E**). The FDP tendon can be seen by itself distal to the insertion of the FDS tendon slips (**F**) before inserting at the base of the distal phalanx (**G**). The digital arteries (green, **C**) are positioned dorsal to the digital nerves (orange, **C**). **H** Sagittal T2 fat-suppressed image demonstrates the levels of axial images in **A**–**G** as well as the FDP tendon insertion at the base of the distal phalanx (blue arrow)

FDS tendon inserts as two slips at the middle phalanx where it acts as the primary flexor of the proximal interphalangeal (PIP) joint. The FDP tendon inserts at the base of the distal phalanx and acts as the primary flexor of the distal interphalangeal (DIP) joint. The tendon position adjacent to the phalanges is maintained by a series of five annular pulleys and three cruciate pulleys, which help maximize mechanical efficiency by decreasing the work of flexion and facilitate smooth tendon gliding [3]. The pulleys are located superficial and palmar to the flexor sheath and include the A1 pulley at the level of the metacarpophalangeal joint, the A2 pulley at the level of the proximal phalanx, and the A4 pulley at the level of the middle phalanx. The vascular supply to the flexor tendons is through direct perfusion from vessels in small tendinous bands called vincula as well as through diffusion from the synovial sheath (Fig. 3) [4–7]. Named components of the vincular system include the vinculum longus superficialis (VLS) and vinculum brevis superficialis (VBS) which supply the FDS tendon and the vinculum longus profundus (VLP) and vinculum brevis profundus (VBP) which supply the FDP tendon. The vincula are not well seen on imaging and injury to these structures is implied by the position of the torn tendon, as will be discussed. The anatomy of the thumb flexor apparatus differs from the fingers with only a single flexor tendon and a different arrangement of pulleys and vincula; injuries to the flexor pollicis longus tendon will not be discussed in this manuscript.

Flexor tendon injuries

Flexor tendon injuries of the index, long, ring, and small fingers are divided into five anatomic zones (Fig. 4, Table 1). Clinical presentation depends on the location and mechanism of injury though limited or absent active flexion at the DIP joint and/or PIP joint should lead the examiner to suspect a flexor tendon injury.

Radiographs are always obtained in the acute setting to evaluate for the presence and size of fracture fragments as well as retained foreign bodies in open injuries. Computed tomography can be obtained to better delineate the anatomy of complex fractures, though it has a limited role in evaluating the extent of a flexor tendon injury. Both ultrasound and MRI can be used to image flexor tendon injuries

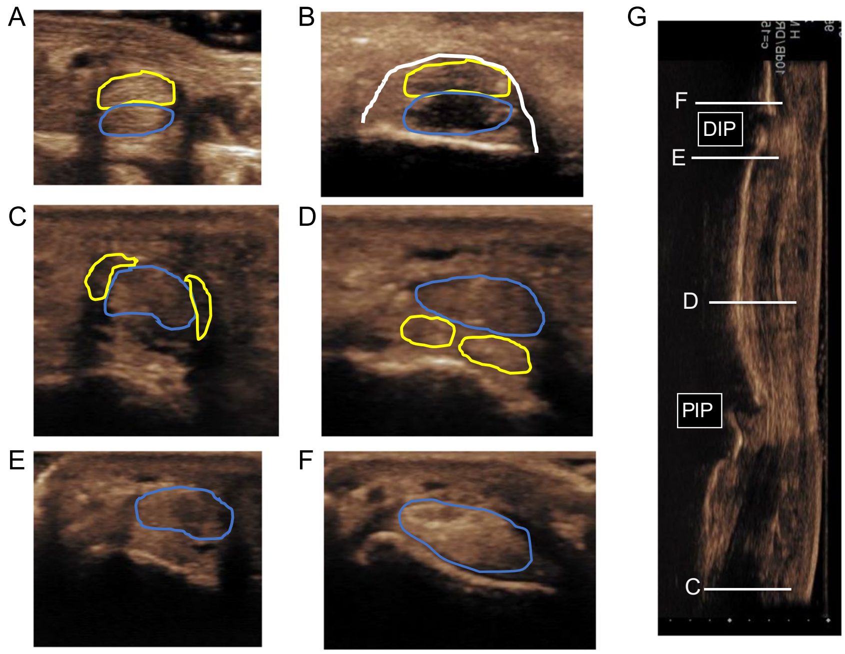

Fig. 2 Flexor tendon anatomy on ultrasound. **A**–**F** Short-axis ultrasound images at the level of the palm (**A**), A1 pulley (curved white line, **B**), proximal phalanx (**C**), mid portion of middle phalanx (**D**), distal portion of middle phalanx (**E**), and base of distal phalanx (**F**) demonstrate anatomy of the flexor tendons. At the level of the palm and A1 pulley (**A**, **B**), the flexor digitorum superficialis (FDS) tendon (yellow) is one tendon and superficial to the flexor digitorum profundus (FDP) tendon (blue). At the level of the proximal phalanx (**C**), the FDS tendon has divided with the FDP tendon passing through the decussation to assume a more volar position. The FDS tendon slips insert at the level of the middle phalanx (**D**). The FDP tendon can be seen by itself distal to the insertion of the FDS tendon slips (**E**) before inserting at the base of the distal phalanx (**F**). **G** Long-axis ultrasound image demonstrates the levels of transverse images in C–F

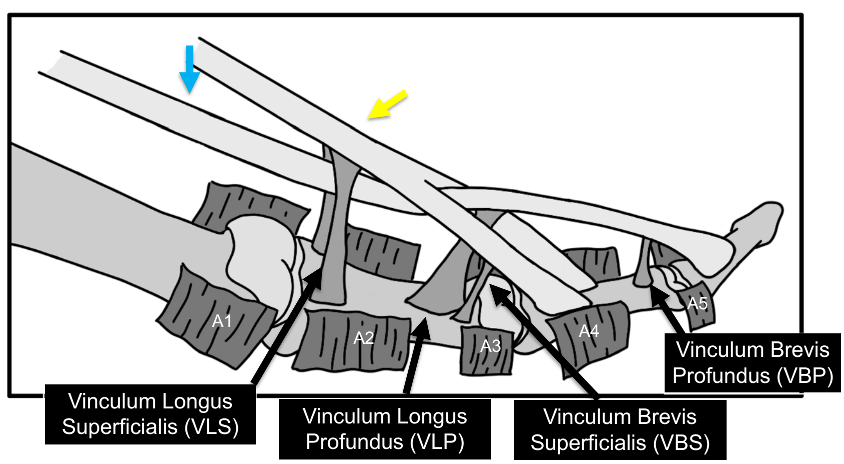

Fig. 3 Diagram demonstrates the anatomy of the vincular system in relation to the flexor digitorum profundus (blue arrow) and flexor digitorum superficialis (yellow arrow) tendons. The annular pulleys are shown sectioned and the flexor sheath has been removed for illustrative purposes. The vincular system plays a key role in the tendons's vascular supply along with diffusion from the synovial tendon sheath. The vincula also play a role in limiting or preventing tendon retraction in some injuries

[8–11]. These modalities are occasionally used in the acute setting, though they are more valuable for the treating surgeon in the subacute/chronic setting as will be discussed. Ultrasound has the advantage of increased spatial resolution when evaluating superficial structures as well as the ability to perform dynamic evaluation, which can be helpful in better delineating tendon tears. We perform ultrasound using high-frequency linear transducers (14–18 MHz) and find the small footprint transducer (hockey stick) especially helpful for imaging the areas of concern while not impeding motion at the interphalangeal joints. MRI allows for better evaluation of the adjacent osseous structures and joints, the status of which can be important when weighing different surgical treatment options. We perform MRI using dedicated hand-wrist coils on 3-T scanners, centering the field of view on the injured digit and including one uninjured digit on either side. Optimal MRI sequences will depend on the scanner being used though our finger MRI protocol includes axial

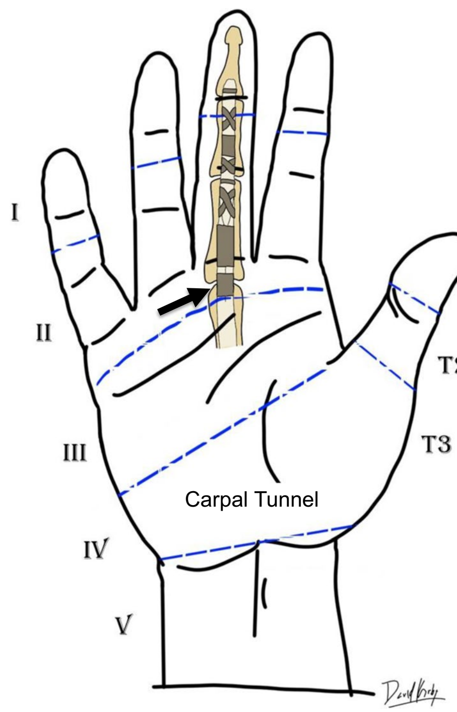

Fig. 4 Diagram demonstrates the five zones of flexor tendon injury in the index, long, ring, and small fingers. The black arrow points to the A1 pulley

proton density and T2 fat-suppressed, coronal proton density and intermediate-weighted fat suppressed, and sagittal intermediate-weighted fat-suppressed sequences. Our field of view always includes the entire flexor tendon sheath and at least the distal portion of the palm.

Zone 1

Zone 1 flexor tendon injuries occur distal to the FDS insertion and involve the FDP tendon and/or distal phalanx. Closed injuries occur when there is forced hyperextension of an actively flexed DIP joint and are referred to as jersey finger. Injuries can be characterized using the Leddy and Packer Classification, which started with three injury types though has been expanded by other authors and now includes five patterns of injury (Fig. 5, Table 2) [12–14]. Key factors in injury characterization, which can be obtained from radiographs and either MRI or US, include the presence and extent of osseous and tendon injury, the location of the torn proximal FDP tendon stump, the length of residual FDP tendon at the distal phalanx, and evidence of associated injuries such as to the digital nerves and digital arteries. While precise localization of the torn FDP tendon stump is ideal, it is most important for our surgeons to know whether the stump is within the tendon sheath, such as in a type 2 injury (Fig. 6), or retracted into the palm, such as in a type 1 injury. This has implications for whether vascularity to the tendon stump is maintained and whether the patient will be a candidate for a primary tendon repair.

Zone 2

Zone 2 flexor tendon injuries occur between the proximal A1 pulley (proximal aspect of the flexor tendon sheath) and the FDS tendon insertion onto the middle phalanx. Injuries in zone 2 are uniquely difficult to manage as the FDP and FDS tendons must be accommodated within the tendon sheath in this location. The repaired tendons have a higher chance of developing adhesions and can catch or trigger when passing through the A2 pulley [15, 16]. Additionally, studies have shown decreased vascularity to the FDP tendon in zone 2, which some feel impedes tendon healing and predisposes to recurrent ruptures [16, 17]. As injuries in zone 2 are most commonly due to lacerations, it is important to evaluate the extent of injury including the presence and extent of the FDP tendon tear, the status of the FDS tendons, and evidence of associated injuries to the digital nerves, digital arteries, and pulley system. Injury to the annular pulleys is suggested when the pulleys are absent, ill-defined, or thickened, or have surrounding edema/fluid as well as when the tendons demonstrate bowstringing [18]. Injuries in zone 2 often involve the FDP and FDS tendons though they can also only involve the FDP tendon due to its superficial location within the tendon sheath [15]. Isolated FDS tendon injuries are exceedingly rare. As in zone 1 flexor tendon injuries, it

Table 1 Flexor tendon injury zones

Zone	Proximal border	Distal border
1	Flexor digitorum superficialis insertion onto middle phalanx	Flexor digitorum profundus insertion onto distal phalanx
2	Proximal margin of A1 pulley (proximal flexor tendon sheath)	Flexor digitorum superficialis insertion onto middle phalanx
3	Distal aspect of carpal tunnel	Proximal margin of A1 pulley (proximal flexor tendon sheath)
4	Proximal aspect of carpal tunnel	Distal aspect of carpal tunnel
5	Myotendinous junction	Proximal aspect of carpal tunnel

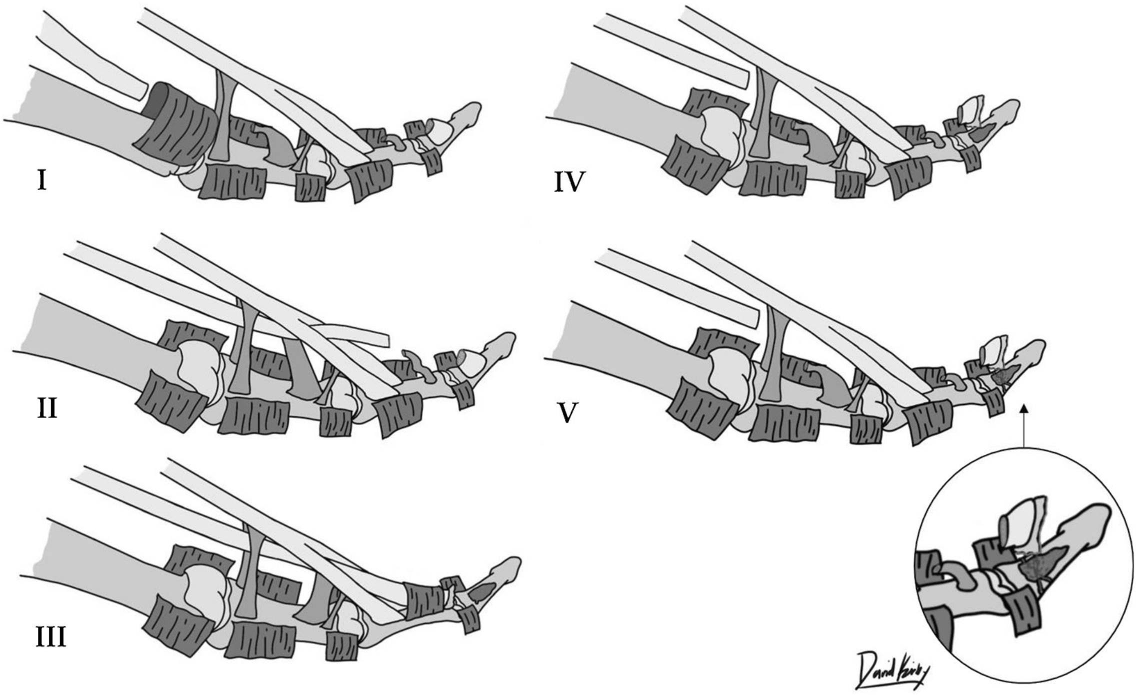

Fig. 5 Diagram demonstrates the Leddy and Packer classification of zone 1 flexor tendon injuries. In type 1 injuries, the tendon is torn and retracted proximal to the A1 pulley. In type 2 injuries, the tendon is torn and remains within the tendon sheath, often at the level of the proximal interphalangeal joint. In type 3 injuries, the tendon insertion at the base of the distal phalanx is avulsed with a fracture fragment remaining distal to the A4 pulley. In type 4 injuries, there is an avulsion fracture and the tendon is torn from the avulsion fracture. Type 5 injuries are the same as type 4 injuries though include an additional, often transverse, distal phalanx fracture

Table 2 Leddy and Packer classification of zone 1 flexor tendon injuries

Type	Description
1	• FDP tendon torn and retracted into palm (proximal to A1 pulley) • VBP and VLP torn
2	• FDP tendon torn and remains within tendon sheath at PIP joint • Can have small avulsion fracture fragment • VBP torn, VLP intact
3	• Avulsion fracture with large, avulsed fragment distal to A4 pulley • VBP and VLP intact
4	• Avulsion fracture and tendon torn from fracture fragment • Variable tendon retraction and status of vincula
5	• Distal phalanx fracture + avulsion fracture and tendon torn from avulsion fracture fragment • Variable tendon retraction and status of vincula

FDP flexor digitorum profundus, *VBP* vincula brevis profundus, *VLP* vincula longus profundus

is essential to locate the torn proximal FDP tendon stump and identify whether it is proximal or distal to the proximal A1 pulley (Fig. 7).

Zones 3, 4, 5

Zone 3 flexor tendon injuries occur between the distal aspect of the carpal tunnel and the proximal A1 pulley. They are almost always due to lacerations and generally have excellent outcomes with direct tendon repair [19]. Zone 4 flexor tendon injuries occur within the carpal tunnel. These are less common injuries due to protection of the overlying flexor retinaculum. Zone 5 injuries occur between the myotendinous junction and the proximal carpal tunnel. These injuries can be accompanied by injuries to the median and ulnar nerves as well as by vascular injury. In general, injuries in zones 3–5 can be treated with direct tendon repair. Injuries close to the carpal tunnel or involving tendon retraction into the carpal tunnel require release of the transverse carpal ligament and distal zone 3 injuries often require release of the A1 pulley to allow for tendon excursion [16]. As the tendons in these zones are not confined to a flexor tendon sheath, the size of the repaired tendon tissue, or repair bulk, is less of a concern and these injuries are less prone to adhesion formation. On imaging studies, it is important to evaluate the extent of injury including the status of the adjacent neurovascular structures.

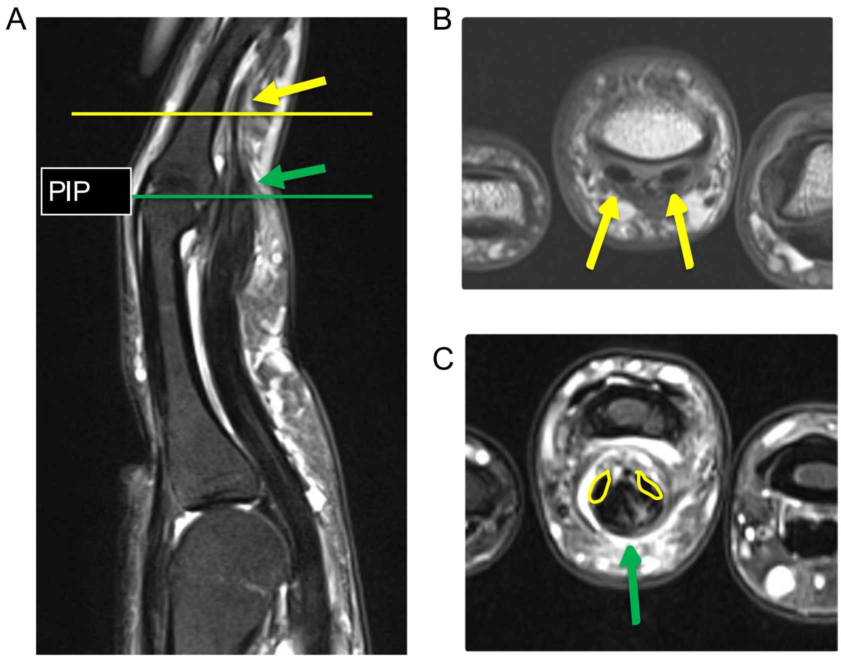

Fig. 6 Zone 1 flexor tendon injury. A 48-year-old man with injury to right ring finger two months prior presenting with inability to flex at the distal interphalangeal joint. Radiographs showed no fracture of the distal phalanx. **A** Sagittal T2 fat-suppressed image demonstrates a torn flexor digitorum profundus (FDP) tendon (green arrow) at the level of the proximal interphalangeal joint (PIP) consistent with a type 2 injury. A flexor digitorum superficialis (FDS) tendon slip is seen distal to the torn FDP tendon (yellow arrow). **B** Axial T1-weighted image at the level of the yellow line in image A demonstrates intact FDS tendon slips (yellow arrows) inserting at the middle phalanx. The FDP tendon is absent. **C** Axial T2 fat-suppressed image at the level of the green line in image A demonstrates the FDP tendon stump (green arrow) superficial to the intact FDS tendon slips, which are outlined in yellow

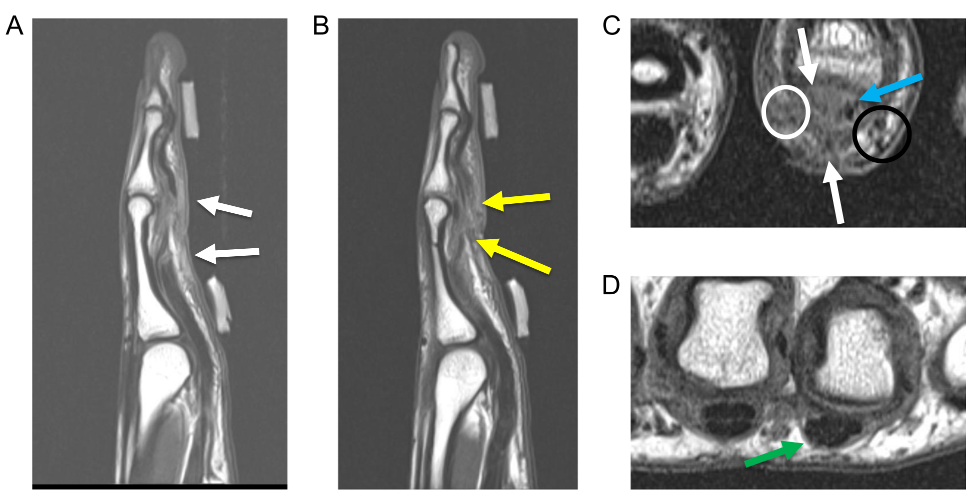

Fig. 7 Zone 2 flexor tendon injury. A 21-year-old man 10 days after falling on a piece of broken glass and lacerating his right ring finger. He presented with inability to flex at the distal interphalangeal joint and loss of sensation radially. **A** Midline sagittal PD image demonstrates a lacerated flexor digitorum profundus (FDP) tendon with a gap between the tendon ends (white arrows). The proximal tendon stump remains within the flexor tendon sheath. **B** Radial sagittal PD image demonstrates a torn radial flexor digitorum superficialis (FDS) tendon slip (yellow arrows). **C** Axial T1 image at the level of the laceration demonstrates torn FDP tendon and radial slip of FDS (white arrows), partially torn ulnar slip of the FDS tendon (blue arrow), and obscured radial neurovascular bundle suggesting injury (white circle). The ulnar neurovascular bundle is intact (black circle). **D** Axial T1 image at the level of the metacarpal heads demonstrates intact flexor tendons deep to the A1 pulley (green arrow)

Treatment of flexor tendon injuries

Treatment options

Upper extremity surgeons have many treatment options when addressing flexor tendon injuries. In general, primary tendon repair is the treatment of choice for acute, complete flexor tendon tears as well as acute, partial flexor tendon tears encompassing greater than 50% of the tendon width [16]. Some surgeons though have achieved good results exploring high-grade partial flexor tendon tears and treating them conservatively without suture repair [20]. Many different repair techniques have been described in the literature which all have the goal of achieving a strong, secure repair with minimal gapping at the repair site, and minimal disruption of tendon vascularity [21, 22].

Flexor tendon reconstruction involves resection of the injured tendon and replacement with a tendon graft, which can come from many different sites. Reconstruction requires a well vascularized, sensate finger without joint contracture, and the ability to comply with an extensive rehabilitation program [23]. Reconstructions can be done as either a one-stage or a two-stage procedure. One-stage reconstructions are less frequently performed as they require an intact, unscarred flexor tendon sheath and competent pulley system though they may be an option in patients with acute injuries and segmental tendon loss [24]. The first stage of a two-stage reconstruction involves resection of the torn tendon and scarring within the tendon sheath, placement of a silicone implant (Hunter rod) into the tendon bed (Fig. 8), and if necessary reconstruction of the annular pulleys. The implant can be placed from the finger tip to either the palm or the forearm depending on the nature of the injury, surgeon preference, and the anticipated graft. The implant is left in place for at least 3 months to allow for formation of a pseudosheath to facilitate gliding of the tendon graft [25]. In the second stage, the rod is removed and the tendon graft is placed into the pseudosheath. This requires that the pseudosheath is mature and the digit is supple and free from scarring or contracture. Grafts can be used from a variety of sites including extrasynovial grafts such as the palmaris longus tendon, plantaris tendon, and the extensor digitorum longus tendons to the 2nd, 3rd, or 4th toes, or intrasynovial grafts such as toe flexors and the FDS tendon. Occasionally, our surgeons will ask for ultrasound imaging to verify the presence of potential tendon grafts to better plan for surgery and minimize time in the operating room (Fig. 9). When asked to do this, we verify the presence of the requested tendon and provide a representative cross-sectional measurement of the tendon. Ultrasound is accurate for identifying the presence of the palmaris and plantaris tendons though there is little research on whether ultrasound can accurately predict graft adequacy [26–28]. Our surgeons harvest the plantaris tendon starting at the level of the medial malleolus and use counter incisions to trace the tendon proximally and achieve optimal graft length.

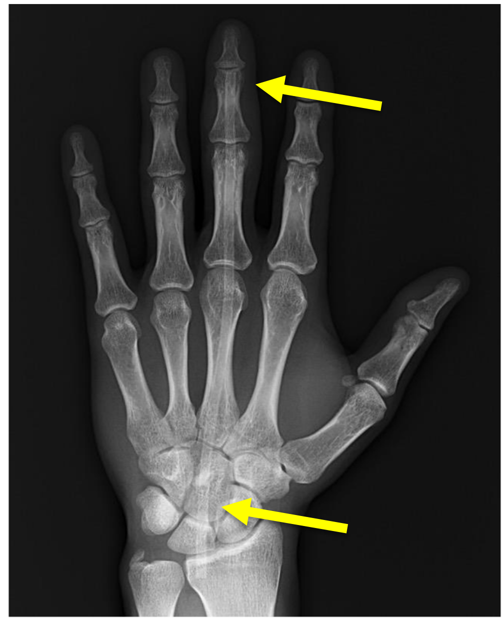

Fig. 8 Frontal radiograph of the left hand demonstrates an intact hunter rod (yellow arrows) extending from the distal forearm to the distal phalanx in a 30-year-old man 4 months status post stage 1 of two-stage long finger flexor tendon reconstruction

Patients with irreparable acute or chronic zone 1 or zone 2 injuries who are not candidates for flexor tendon reconstruction can also be treated with DIP joint arthrodesis or DIP and PIP joint arthrodesis, which can be combined with either tenodesis or tendon excision. DIP joint arthrodesis is commonly offered to patients with chronic zone 1 flexor tendon injuries who have pain, instability, or hyperextension at the DIP joint. Some surgeons feel these procedures provide a more predictable outcome than flexor tendon reconstruction in most patients [6, 16].

Treatment considerations

Decision-making in flexor tendon injuries is complex and relies on a number of factors. These include the age and functional demands of the patient, the chronicity of the injury, the extent of disruption to the tendon's vascular supply, the function of the PIP joint and status of the FDS tendons, the presence and size of osseous fragments in zone 1 injuries, and associated neurovascular injuries.

Treatment of zone 1 flexor tendon injuries depending on injury type and chronicity is outlined in Table 3. US or MRI

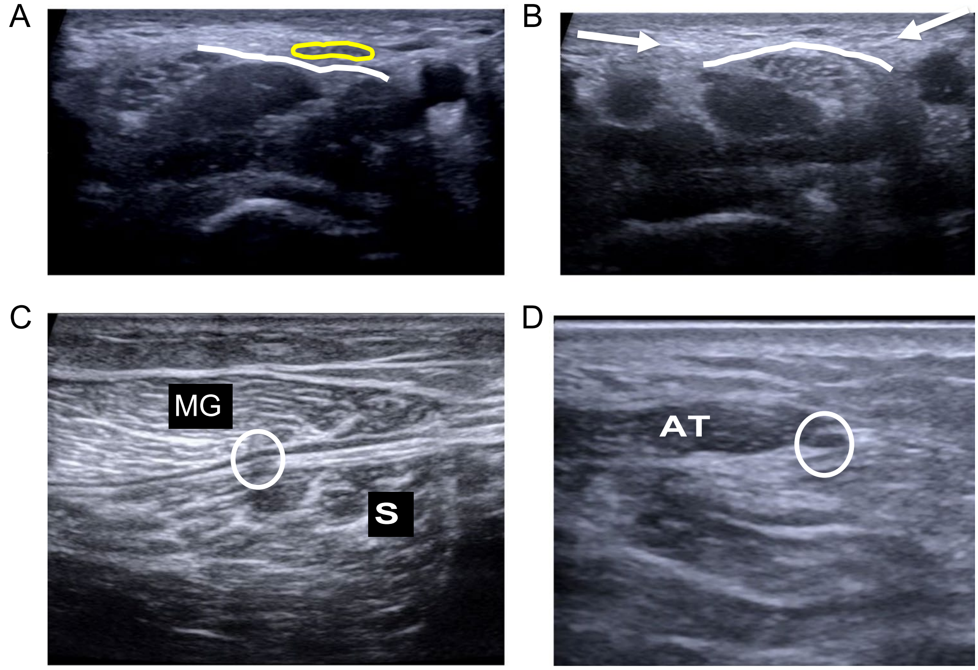

Fig. 9 A 39-year-old man with a chronic zone 2 flexor tendon tear. Ultrasound was ordered to verify presence of bilateral palmaris longus and left plantaris tendons prior to flexor tendon reconstruction. **A**–**B** Short-axis US of the right wrist (**A**) demonstrates an intact palmaris longus tendon (yellow oval) superficial to the flexor retinaculum (white line). The palmaris longus tendon is absent in the left wrist (white arrows, **B**). **C**–**D** Short-axis US of the left calf (**C**) and left ankle (**D**) demonstrate an intact plantaris tendon (white circle). In the calf, the tendon is between the medial head gastrocnemius (MG) and soleus (S) muscles and in the ankle the tendon is at the medial aspect of the Achilles tendon (AT)

Table 3 Treatment of zone 1 flexor tendon injuries based on Leddy and Packer classification

Type	Description
1	• Vascular supply to tendon is lost and pulley system collapses over time • Repair ideally within 7 days to avoid tendon contracture • > 1 cm tendon at distal phalanx—primary tendon repair • < 1 cm tendon at distal phalanx—tendon to bone repair
2	• Vascular supply to tendon remains intact • Repair within 6 weeks
3	• Fracture fixation within 6 weeks
4-5	• Fracture fixation then address tendon as in type 1 or 2 injuries depending on status of vascular supply to tendon
Chronic injuries (>6 weeks)	• Options—two-stage reconstruction, DIP arthrodesis, non-operative management

are rarely performed in the acute setting at our institution as many of our surgeons plan on repairing these injuries urgently in case the torn FDP tendon stump is retracted into the palm and its vascular supply is lost. If there are complicating factors that may delay the injury being addressed or if there is concern for either a type IV or type V injury, either US or MRI helps dictate the timing of surgery with the goal of being able to offer these patients a primary repair within an acceptable time frame. Pre-operative US or MRI becomes more important in the subacute and chronic settings where a retracted tendon with lost vascular supply becomes irreparable and the patient's options are limited to reconstruction to regain active flexion at the DIP joint.

US or MRI are used in a similar fashion for patients with zone 2 flexor tendon injuries, with the location of the torn proximal FDP tendon stump dictating whether the patient is a candidate for primary tendon repair in the subacute setting. In these patients, the status of the FDS tendons and clinical function of the PIP joint are also key factors in treatment decision-making. If a patient is a candidate for a primary FDP tendon repair and one FDS tendon slip is torn, the surgeon has the option to either repair or resect that tendon slip in order to best accommodate the repaired FDP tendon within the tendon sheath. If both FDS tendon slips are torn, surgeons will often repair one of the tendon slips and resect the other to best accommodate the repaired tendons.

In patients with either zone 1 flexor tendon injuries or zone 2 flexor tendon injuries with preserved function at the PIP joint who are not candidates for a primary tendon repair, the decision to offer a two-stage reconstruction is complex and controversial. This is because of the extensive rehabilitation and patient compliance required to achieve an excellent outcome as well as the risk that the reconstruction will compromise function at the intact PIP joint. For these reasons, many surgeons only offer flexor tendon reconstruction in young patients (ages 10–21) and in patients who require active flexion at the DIP joint such as athletes, musicians, and skilled laborers. Other surgeons though advocate that many patients above the age of 21 can be good candidates for reconstruction [29].

Post-operative care and treatment complications

After patients undergo primary flexor tendon repair, early controlled mobilization is encouraged to improve tendon healing and limit the possibility of developing tendon scarring and adhesions. Post-operative imaging is not routinely obtained though it will be ordered if the patient is unable to flex at the DIP joint, demonstrates limited or loss of active range of motion, or demonstrates signs suspicious for infection. It is very difficult to clinically differentiate a recurrent flexor tendon tear from the development of adhesions/scarring as both processes can present with new inability to flex at the DIP joint [30]. In the setting of suspected rerupture or development of adhesions, we strongly advocate for using ultrasound as this allows for real-time dynamic imaging to evaluate the continuity of the repaired tendon and the ability of the repaired tendon to glide within the tendon sheath [31]. While a recent cadaveric study comparing MRI and US in repaired flexor tendons concluded that MRI was more accurate for identifying small tendon gaps, we have observed that it can be difficult to evaluate the continuity of a newly repaired tendon on MRI likely due to post-operative edema and remodeling around the repair site (Fig. 10) [32]. Ultrasound has been shown to be very accurate in this setting with a prior study using surgical correlation reporting 96% accuracy in differentiating a recurrent tendon tear from adhesions in patients after flexor tendon repair [31].

Recurrent tears occur in about 4% of primary tendon repairs and 14% of two-stage reconstructions [33, 34]. Adhesions are said to occur in 4% of primary tendon repairs though have a higher incidence in zone 2 injuries where about 15% of patients undergo subsequent tenolysis [33, 35]. Differentiation of a recurrent tear from adhesions is important due to the differences in management. Adhesions are managed with aggressive therapy to increase active range of motion. Many patients ultimately require tenolysis, which is not performed within the first 3 months of the primary tendon repair due to the risk of compromising the vascular supply to the healing repair. If a recurrent tear is identified, the treating surgeon has a difficult decision in regard to whether and when to attempt a revision repair. Revision repairs have worse outcomes than primary repairs and ultimately tendon reconstruction or tenodesis and DIP arthrodesis might be better options [36]. In the acute post-operative setting, surgeons will often offer the patient a revision repair while discussing other surgical treatment options in the event that a revision repair is not possible.

When preforming ultrasound in patients after a primary tendon repair, our technique is to first evaluate

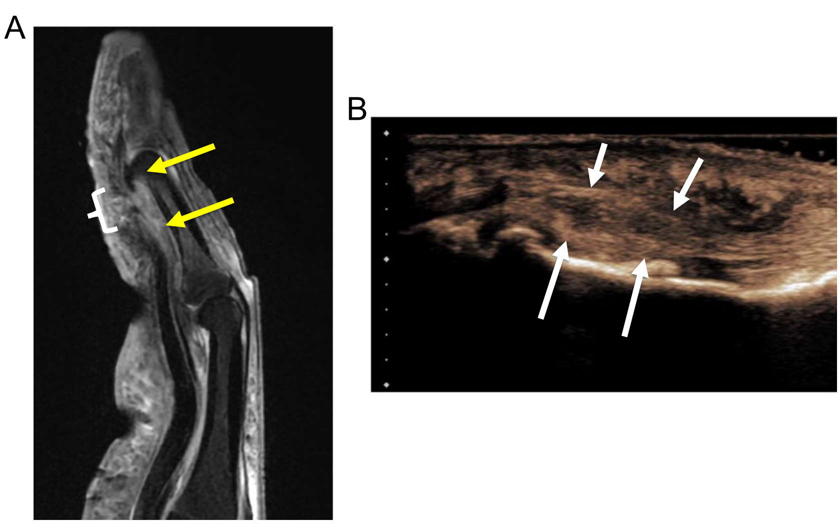

Fig. 10 A 35-year-old man 3 weeks status post flexor tendon repair. He presented to clinic with significantly decreased active range of motion at the distal interphalangeal joint compared with at his two-week postoperative visit. **A** Sagittal T2 fat-suppressed image demonstrates heterogeneous signal of the flexor tendon about the repair site (yellow arrows) with an apparent intermediate signal gap at the repair (white bracket). Ultrasound was recommended for further evaluation. **B** Long-axis image from US performed one day later demonstrates mildly hypoechoic though intact tendon tissue across the repair with no tendon gap. Dynamic evaluation showed intact tendon at the repair site (see supplemental materials). The patient underwent intensive therapy with improvement in active motion and did not require subsequent surgery

the continuity of the tendon longitudinally and in short axis to ensure there is no gap or tendon retraction. We then look for adhesions/scarring which is characterized by heterogeneous soft tissue about the tendon which impedes tendon gliding with dynamic movement at the DIP joint. We see this occur most commonly about the primary repair site (Fig. 11). Unfortunately, the continuity of the repair can be difficult to evaluate in these areas of scarring. This is why we prefer ultrasound to better identify the tendon ends and evaluate for motion across the repair site with dynamic movements (Fig. 12). We most often perform dynamic evaluation by passively flexing and extending the digit of concern at the DIP joint while preventing motion at the PIP and MCP joints. If the patient is able to actively flex at the DIP joint, we will image them during active flexion. The majority of patients though are referred for ultrasound with limited or no active motion at the DIP joint. Aggressive dynamic evaluation in newly repaired tendons, such as forcibly moving the finger into a position against resistance, should be avoided however as there is a potential risk of causing damage to the tendon. There is no specific time frame after a repair when dynamic ultrasound evaluation is contraindicated. In patients who have undergone a tendon reconstruction, our focus is to evaluate the continuity of the tendon graft and ensure the graft is secure at both the distal phalanx and the proximal coaptation site, where we often focus our dynamic evaluation.

Infection is an uncommon complication with a low incidence in primary tendon repairs though a 4% incidence after two-stage tendon reconstructions [34]. In cases of suspected infection, we recommend MRI if there is concern for involvement of the osseous structures and advocate for contrast if there is concern for abscess formation. Treatment is usually irrigation and debridement followed by intravenous antibiotics (Fig. 13).

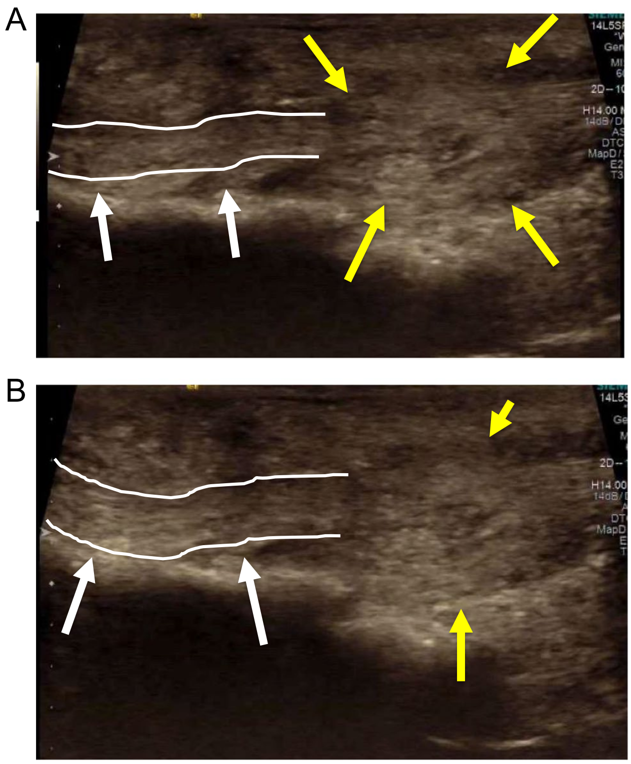

Fig. 11 Post-operative adhesions. A 37-year-old man 4 months status post zone 2 flexor tendon repair with decreased active flexion at the distal interphalangeal joint. **A** Long-axis US image in extension demonstrates heterogeneous soft tissue (yellow arrows) about the intact tendon repair. Notice the more distal tendon has a taut appearance in extension (white arrows). **B** Long-axis US image with flexion at the distal interphalangeal joint demonstrates no tendon gliding at the repair site (yellow arrows) consistent with adhesions. Notice the more distal tendon begins to buckle (white arrows) when tendon gliding is blocked by adhesions. These findings are better demonstrated on dynamic evaluation (see supplemental materials)

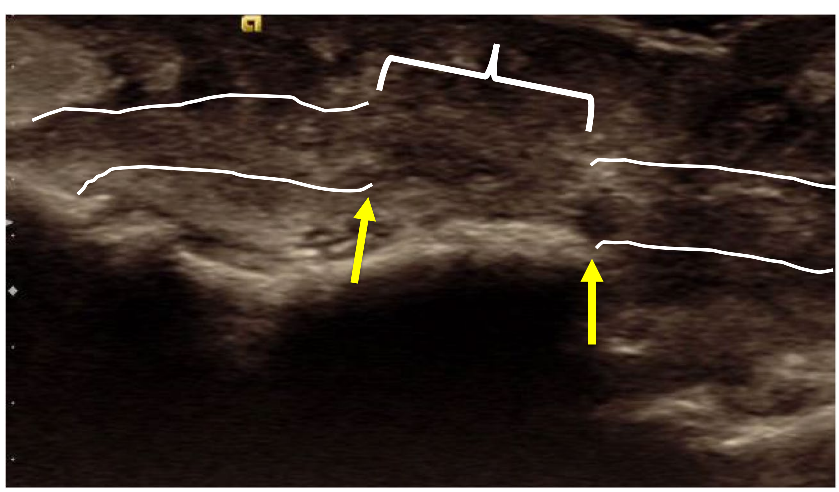

Fig. 12 Recurrent flexor tendon tear. A 48-year-old man 8 weeks status post zone 2 flexor tendon repair with loss of active flexion at the distal interphalangeal joint. Long-axis US image demonstrates a recurrent flexor tendon tear with the frayed tendon ends (yellow arrows) separated by a gap of heterogenous tissue (white bracket). Dynamic evaluation showed no motion across the tendon gap (see supplemental materials)

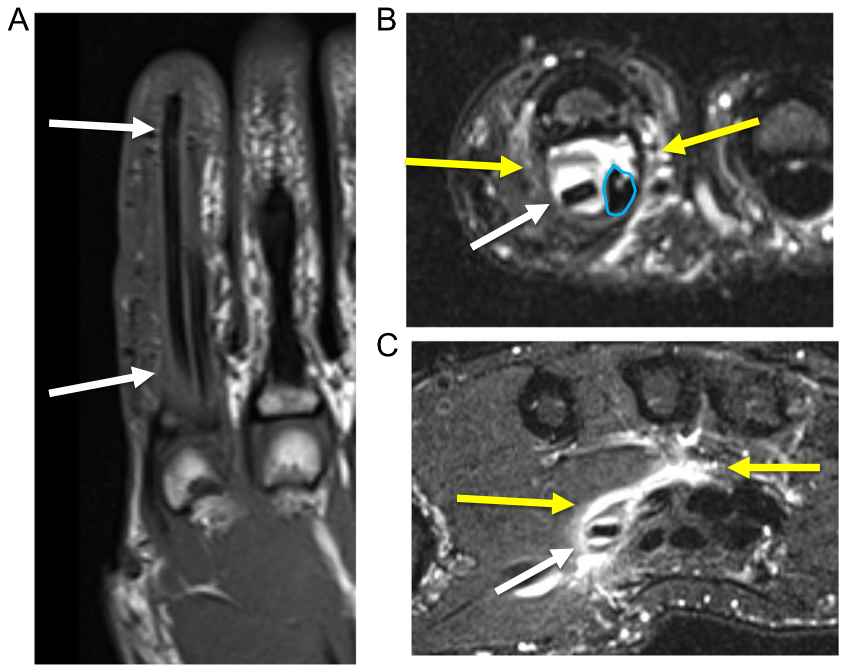

Fig. 13 Post-operative infection. A 39-year-old man with increasing pain and swelling 2.5 months after stage 1 of a two-stage index finger flexor tendon reconstruction. **A** Coronal T1 image shows an intact Hunter rod within the flexor tendon sheath (white arrows). **B** Axial T2 fat-suppressed image at the level of the proximal phalanx shows tenosynovitis (yellow arrows) about the intact Hunter rod (white arrow) and FDS tendons (blue circle). **C** Axial T2 fat-suppressed image at the level of the palm shows edema (yellow arrows) about the intact Hunter rod. The patient was taken to the OR for tenosynovectomy and Hunter rod removal with cultures growing Staph Epidermidis

Conclusion

Imaging plays a key role in the diagnosis and management of flexor tendon injuries, providing important information for the treating surgeon. In our practice, imaging is commonly performed in patients with subacute and chronic flexor tendon injuries as well as in patients with suspected complications after flexor tendon repair or reconstruction. Radiologists must understand the role of imaging in the management of these patients in order to produce helpful reports and guide patient management.

References

1. Clayton RAE, Court-Brown CM. The epidemiology of musculoskeletal tendinous and ligamentous injuries. Injury. 2008;39:1338–44.
2. Manninen M, Karjalainen T, Määttä J, Flinkkilä T. Epidemiology of flexor tendon injuries of the hand in a Northern Finnish population. Scand J Surg. 2016;106:278–82.
3. Doyle JR. Anatomy of the flexor tendon sheath and pulley system: a current review. J Hand Surg. 1989;14:349–51.
4. Armenta E, Lehrman A. The vincula to the flexor tendons of the hand. J Hand Surg. 1980;5:127–34.
5. Ochiai N, Matsui T, Miyaji N, Merklin RJ, Hunter JM. Vascular anatomy of flexor tendons. I. Vincular system and blood supply of the profundus tendon in the digital sheath. J Hand Surg. 1979;4:321–30.
6. Ruchelsman DE, Christoforou D, Wasserman B, Lee SK, Rettig ME. Avulsion injuries of the flexor digitorum profundus tendon. J Am Acad Orthop Surg. 2011;19:152–62.
7. Manske PR, Lesker PA. Nutrient pathways of flexor tendons in primates. J Hand Surg. 1982;7:436–44.
8. Stephens AR, Buterbaugh KL, Gordon JA, et al. Comparison of magnetic resonance imaging and ultrasound evaluations of zone II partial flexor tendon lacerations. J Ultrasound Med. 2021;40:1651–6.
9. Alvarez DA, Ballard DH, Carroll T, Frilot C, Simoncini AA. Ultrasound localization of lacerated flexor tendon ends in the hand: a cadaveric study. Skelet Radiol. 2019;48:1941–6.
10. Lapegue F, Andre A, Brun C, et al. Traumatic flexor tendon injuries. Diagn Interv Imaging. 2015;96:1279–92.
11. Ravnic DJ, Galiano RD, Bodavula V, Friedman DW, Flores RL. Diagnosis and localization of flexor tendon injuries by surgeon-performed ultrasound: a cadaveric study. J Plast Reconstr Aesthet Surg. 2011;64:234–9.
12. Leddy JP, Packer JW. Avulsion of the profundus tendon insertion in athletes. J Hand Surg. 1977;2:66–9.
13. Al-Qattan MM. Type 5 avulsion of the insertion of the flexor digitorum profundus tendon. J Hand Surg. 2001;26:427–31.
14. Smith JH Jr. Avulsion of a profundus tendon with simultaneous intraarticular fracture of the distal phalanx - case report. J Hand Surg. 1981;6:600–1.
15. Dy CJ, Daluiski A. Update on zone II flexor tendon injuries. J Am Acad Orthop Surg. 2014;22:791–9.
16. Klifto CS, Capo JT, Sapienza A, Yang SS, Paksima N. Flexor tendon injuries. J Am Acad Orthop Surg. 2018;26:e26–35.
17. Lundborg G, Myrhage R, Rydevik B. The vascularization of human flexor tendons within the digital synovial sheath region - structural and functional aspects. J Hand Surg. 1977;2:417–27.
18. Berrigan W, White W, Cipriano K, Wickstrom J, Smith J, Hager N. Diagnostic imaging of A2 pulley injuries: a review of the literature. J Ultrasound Med. 2022;41:1047–59.
19. Al-Qattan MM. Flexor tendon repair in zone III. J Hand Surg Eur. 2010;36:48–52.
20. Al-Qattan MM. Conservative management of zone II partial flexor tendon lacerations greater than half the width of the tendon. J Hand Surg Am. 2000;25:1118–21.

21. Strickland JW. Development of flexor tendon surgery: twenty-five years of progress. J Hand Surg Am. 2000;25:214–35.
22. Strickland JW. Flexor tendon injuries: I. Foundations of Treatment. J Am Acad Orthop Surg. 1995;3:44–54.
23. Samora JB, Klinefelter RD. Flexor tendon reconstruction. J Am Acad Orthop Surg. 2016;24:28–36.
24. Fletcher DR, McClinton MA. Single-stage flexor tendon grafting: refining the steps. J Hand Surg Am. 2015;40:1452–60.
25. Hunter JM, Salisbury RE. Flexor-tendon reconstruction in severely damaged hands: a two-stage procedure using a silicone-dacron reinforced gliding prosthesis prior to tendon grafting. JBJS. 1971;53:829–58.
26. Jakubietz MG, Jakubietz DF, Gruenert JG, Zahn R, Meffert RH, Jakubietz RG. Adequacy of palmaris longus and plantaris tendons for tendon grafting. J Hand Surg. 2011;36:695–8.
27. Simpson SL, Hertzog MS, Barja RH. The plantaris tendon graft: an ultrasound study. J Hand Surg. 1991;16:708–11.
28. Johnson CC, Vutescu ES, Miller TT, Nwawka OK, Lee SK, Wolfe SW. Ultrasound determination of presence, length and diameter of the palmaris longus tendon. J Hand Surg Eur. 2018;43:948–53.
29. McClinton MA, Curtis RM, Wilgis EFS. One hundred tendon grafts for isolated flexor digitorum profundus injuries. J Hand Surg. 1982;7:224–9.
30. Matloub HS, Dzwierzynski WW, Erickson S, Sanger JR, Yousif NJ, Mouneke V. Magnetic resonance imaging scanning in the diagnosis of zone II flexor tendon rupture. J Hand Surg Am. 1996;21:451–5.
31. Budovec JJ, Sudakoff GS, Dzwierzynski WW, Matloub HS, Sanger JR. Sonographic differentiation of digital tendon rupture from adhesive scarring after primary surgical repair. J Hand Surg Am. 2006;31:524–9.
32. Renfree KJ, Dahiya N, Kransdorf MJ, Zhang N, Patel KA, Drace PA. Comparative accuracy of 1.5T MRI, 3T MRI, and static ultrasound in diagnosis of small gaps in repaired flexor tendons: a cadaveric study. J Hand Surg Am. 2021;46:287–94.
33. Dy CJ, Hernandez-Soria A, Ma Y, Roberts TR, Daluiski A. Complications after Ffexor tendon repair: a systematic review and meta-analysis. J Hand Surg. 2012;37:543–551.e1.
34. Wehbé MA, Mawr B, Hunter JM, Schneider LH, Goodwyn BL. Two-stage flexor-tendon reconstruction. Ten-year experience. JBJS. 1986;68:752–63.
35. Civan O, Gürsoy M, Cavit A, Özcanlı H, Karalezli M. Tenolysis rate after zone 2 flexor tendon repairs. Jt Dis Relat Surg. 2020;31:281–5.
36. Elliot D, Giesen T. Treatment of unfavourable results of flexor tendon surgery: ruptured repairs, tethered repairs and pulley incompetence. Indian J Plast Surg. 2013;46:458–71.