MR Imaging of Ligament and Tendon Injuries of the Fingers[1]

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CME FEATURE

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LEARNING OBJECTIVES FOR TEST 1

After reading this article and taking the test, the reader will be able to:

- Describe the ligamentous and tendinous anatomy of the fingers at MR imaging.
- List the most common ligament and tendon injuries of the fingers.
- Recognize the MR imaging features of these lesions and discuss the role of MR imaging in their evaluation.

Magnetic resonance (MR) imaging can provide important information for diagnosis and evaluation of soft-tissue trauma in the fingers. An optimal imaging technique should include proper positioning, dedicated surface coils, and specific protocols for the suspected abnormalities. Familiarity with the fine anatomy of the normal finger is crucial for identifying pathologic entities. MR imaging is a powerful method for evaluating acute and chronic lesions of the stabilizing articular elements (volar plate and collateral ligaments) of the fingers and thumbs, particularly in the frequently affected proximal interphalangeal and metacarpophalangeal joints. As in other body regions, MR imaging is also useful for depicting traumatic conditions of the extensor and flexor tendons, including injuries to the pulley system. In general, normal ligaments and tendons have low signal intensity on MR images, whereas disruption manifests as increased signal intensity. Radiologists need to understand the full spectrum of finger abnormalities and associated MR imaging findings.

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Abbreviations: DIP = distal interphalangeal, FDP = flexor digitorum profundus, FDS = flexor digitorum superficialis, MCP = metacarpophalangeal, PIP = proximal interphalangeal, UCL = ulnar collateral ligament

Index terms: Fingers and toes, 43.92 • Fingers and toes, injuries, 43.489 • Fingers and toes, MR, 43.1214 • Hand, injuries, 43.489 • Joints, injuries, 437.489 • Ligaments, injuries, 43.489 • Tendons, injuries, 43.489

RadioGraphics 2002; 22:237–256

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Introduction

Finger injuries are one of the most common traumatic injuries in both sports and work activities (1,2). Magnetic resonance (MR) imaging has fine soft-tissue contrast resolution and multiplanar capability and is thus very useful in diagnosing these lesions.

MR imaging allows optimal assessment of the condition of tendons (3–7), thus making it possible to evaluate the presence of a tear, the number of affected tendons, the extent of tendon retraction, and the presence of associated lesions. This information is used to determine the correct surgical plan and surgical approach and is especially useful for closed fractures. MR imaging is also very useful for diagnosis of a Stener lesion after tearing of the ulnar collateral ligament (UCL) of the thumb (8–10) and diagnosis of injuries of the pulley system (11,12). In addition, MR imaging may be used to assess lesions of the capsule and ligament in diagnosis of traumatic lesions involving the proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joints (13), especially in ambiguous or clinically equivocal cases or cases with negative results at plain radiography.

In this article, we review the normal anatomy of the finger together with the clinical and MR imaging findings of the most frequent soft-tissue injuries, which are divided into articular and tendon injuries. Articular injuries include volar plate and collateral ligament lesions of the PIP and MCP joints. Trauma to the extensor and flexor tendons can result in open or closed injuries. The most frequent of the latter are mallet finger deformity, boutonnière deformity, dislocation of the extensor tendon at the MCP joint, and avulsion of the flexor digitorum profundus tendon from the distal phalanx. Injuries of the pulley system are also described.

MR Imaging

Recently, several investigators have reported that MR imaging is an accurate method for evaluation of the anatomy and pathologic conditions of the finger. Hergan et al (9) reported a sensitivity and specificity of 100% for assessment of thumb UCL lesions in 17 patients, whereas Spaeth et al (10) reported a sensitivity of 100% and specificity of 94% for detection of displaced UCL fractures in 16 cadaveric specimens. Rubin et al (5) assessed tendinous pathologic conditions and reported a sensitivity of 92% and specificity of 100% for diagnosis of 12 high-grade flexor tendon tears in cadavers. Drapé et al (6) reported a sensitivity and specificity of 100% for diagnosis of frank tendinous ruptures after flexor tendon repair and a sensitivity of 91% and specificity of 100% for diagnosis of peritendinous adhesions in 63 injured fingers. More recently, Hauger et al (12) performed a study in cadavers and demonstrated direct identification of A2 (proximal phalanx) and A4 (middle phalanx) pulleys in 12 of 12 cases (100%) and direct diagnosis of an abnormal pulley in 100% (A2) and 91% (A3) of 33 cases. The extensor system has not been reviewed or assessed as extensively as the flexor system. However, Drapé et al (7) reported a sensitivity of 89%–92% for T2-weighted MR imaging in evaluation of normal sagittal bands in the extensor hood.

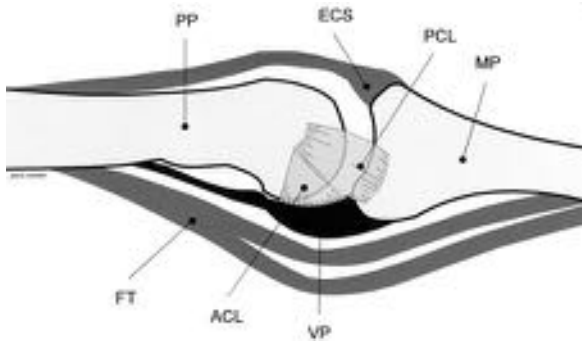


Figure 1. Anatomy of the PIP joint. Drawing (lateral view) shows the accessory collateral ligament (*ACL*), extensor central slip (*ECS*), flexor tendons (*FT*), middle phalanx (*MP*), proper collateral ligament (*PCL*), proximal phalanx (*PP*), and volar plate (*VP*).

MR imaging was performed on a 0.35-T open system (Opart; Toshiba America MRI, San Francisco, Calif). A dedicated coil for studying small parts of the limbs was used to enhance spatial resolution (flexible small parts coil for Opart; Toshiba America MRI). The open system allowed comfortable supine positioning of the patient, with the arm at the side of the body, thus reducing motion artifacts and placing the hand within the magnetic field. Routine MR imaging of the finger was performed in the axial, sagittal, and coronal planes in relation to the MCP and PIP joints of the extended finger. In some cases, sagittal images were obtained with flexion of the affected finger.

T1-weighted images (repetition time msec/echo time msec = 450/15), T2*-weighted gradient-echo images (600/34, 25° flip angle), and short inversion time inversion-recovery images (1,900/40, 95-msec inversion time) were obtained with an 8–9-cm field of view, a 256/320 × 192/256 acquisition matrix, two to three signals acquired, and a section thickness of 3–4 mm with no gap. In addition, 1–2-mm-thick sections were obtained with a three-dimensional T1-weighted gradient-echo pulse sequence (35/5, 70° flip angle).

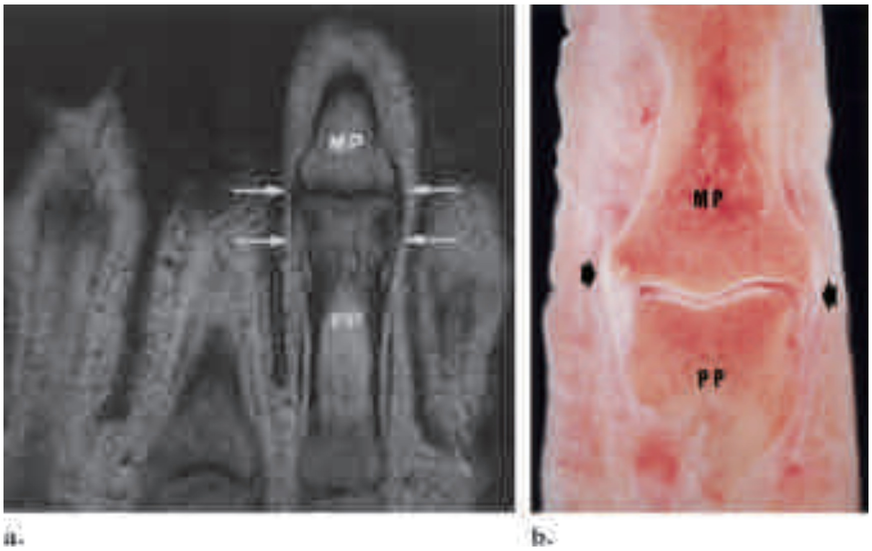


Figure 2. Collateral ligaments of the PIP joint. *MP* = middle phalanx, *PP* = proximal phalanx. **(a)** Coronal T1-weighted MR image shows the collateral ligaments (arrows). **(b)** Photograph of a coronal cross section of a cadaveric finger shows the collateral ligaments (arrows).

Figure 3. Volar plate of the PIP joint. *MP* = middle phalanx, *PP* = proximal phalanx. **(a)** Sagittal T1-weighted MR image shows the volar plate (arrow). **(b)** Photograph of a sagittal cross section of a cadaveric finger shows the volar plate (arrow).

PIP Joint

Anatomy

The PIP joint is a hinged joint with a bicondylar anatomy that allows a wide range of flexion and extension movements (14). The main stabilizers of the joint are the surrounding soft tissues, especially the collateral ligaments and the volar plate (Fig 1) (15). The extensor mechanism, flexor tendons, and retinacular ligaments play a major role in dynamic stability. The collateral ligament complex consists of the collateral ligament proper and an accessory collateral ligament. The former begins at the dorsolateral aspect of the head of the proximal phalanx and inserts at the volar and lateral aspects of the base of the middle phalanx. The latter starts from the same area but inserts at the volar plate. The proper collateral ligament is taut in flexion, whereas the accessory collateral ligament is taut in extension. The volar plate is a thick fibrocartilaginous structure that constitutes the palmar aspect of the PIP joint capsule. Distally, it is firmly attached to the volar lip of the base of the middle phalanx. Proximally, the attachment of the volar plate to the proximal phalanx is more elastic and is U-shaped due to two lateral bands, which are called the "checkrein" ligaments. The volar plate prevents hyperextension of the PIP joint (15). Dorsally, the PIP joint is stabilized by the dorsal extensor apparatus, which consists of a central slip that inserts on the dorsal tubercle of the middle phalanx and lateral slips that are connected by retinacular ligaments.

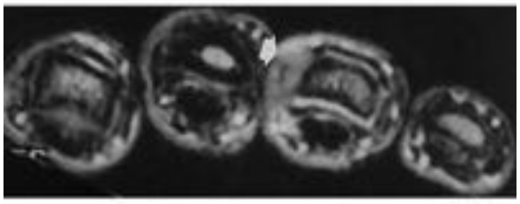
On MR images, normal collateral ligaments appear as sharply defined low-signal-intensity bands extending from the proximal phalanx to the middle phalanx (Fig 2). They are best visualized in the coronal projection. The volar plate is a low-signal-intensity structure that is best seen in a sagittal plane (Fig 3).

Injuries

The PIP joint is the most commonly injured joint in the hand, and its range of motion usually decreases after injury. From a clinical point of view, we classified PIP joint injuries in terms of instability in the coronal plane and instability in the sagittal plane.

Instability in the Coronal Plane.—When an abducting or adducting force is applied to the PIP joint while the finger is extended, three main injuries may occur: a ligamentous sprain with no loss of articular stability, a partial ligamentous tear with laterolateral articular instability, and a complete ligamentous rupture with major instability and articular luxation. The latter is usually associated with total or partial avulsion of the volar plate from the base of the middle phalanx. Treatment, which may be conservative or surgical, is still a matter of controversy (16,17). MR imaging criteria for diagnosis of acute collateral ligament tears include discontinuity, detachment, or thickening of the ligament together with increased intraligamentous signal intensity on T2-weighted images, which is indicative of edema or hemorrhage (Fig 4). Obliteration of the fat planes around the ligament and extravasation of joint fluid into the adjacent soft tissues may also be observed. Chronic tears often demonstrate thickening of the ligament, which is probably secondary to scar formation. Thinning, elongation, or a wavy contour of the ligament may also be seen.

a.



b.

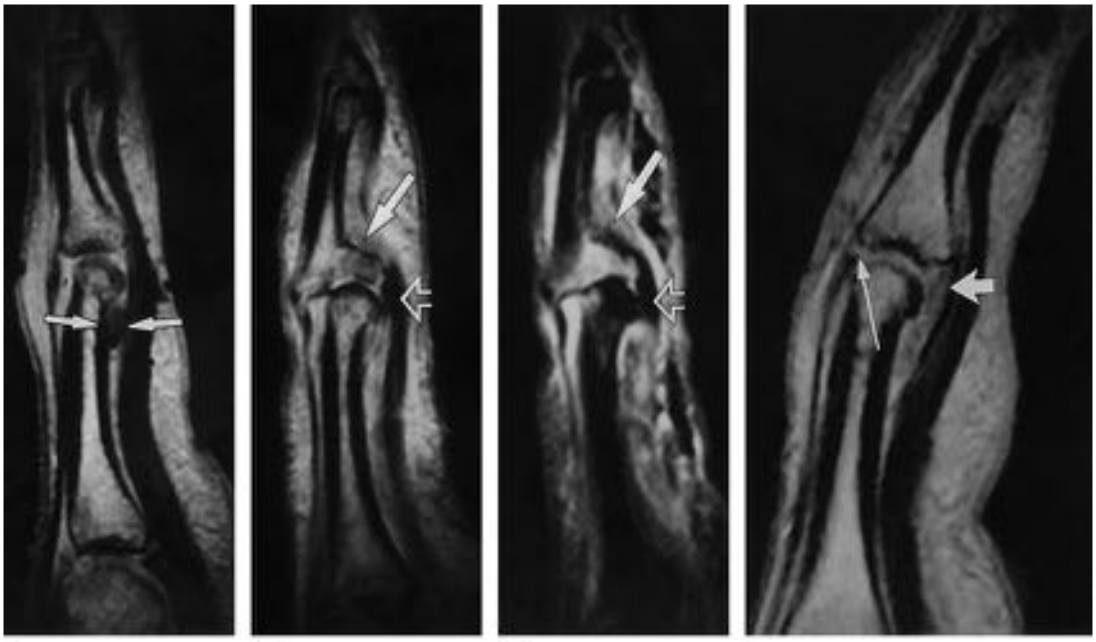
Figure 4. Tear of the collateral ligament of the PIP joint. Coronal **(a)** and axial **(b)** T2-weighted MR images show a complete proximal tear of the radial collateral ligament (arrows). The tear appears as a complete interruption of the ligamentous fibers with intra- and periligamentous high signal intensity secondary to edema, hemorrhage, and probable extravasation of intraarticular fluid.

Instability in the Sagittal Plane.—Instability in the sagittal plane is caused by hyperextension of the PIP joint or rotational longitudinal compression.

Lesions caused by hyperextension are the lesions most frequently seen in sports practice and are sometimes associated with major articular instability. These lesions include different degrees of dorsal articular displacement, which are divided into three types according to the degree of articular instability (type III is a fracture-dislocation of the base of the middle phalanx) (15,17).

In type I lesions, hyperextension results in avulsion of the volar plate from the base of the middle phalanx or, less frequently, from the proximal insertion point of the checkrein ligaments on the proximal phalanx. With no treatment, the natural evolution of distal disruption of the volar plate from the middle phalanx is hyperextension of the PIP joint, which causes a swan-neck deformity due to articular injury (2). Conversely, the natural evolution of proximal disruption of the volar plate from the proximal phalanx causes a flexion deformity of the PIP joint, the so-called pseudoboutonnière deformity (16), with an intact extensor mechanism. MR imaging findings of injury to the volar plate include nonhomogeneous signal intensity on T1- and T2-weighted images, together with thickening and contour irregularities. Disrupted attachment with a gap is observed when avulsion of the volar plate takes place (Fig 5).

In type II lesions, involvement of the periarticular soft tissues is more extensive, with volar plate avulsion and a major split between the components of the collateral ligament complex. The joint shows a higher loss of stability than in type I lesions, as dorsal subluxation or even luxation of the middle phalanx may take place due to traction by the extensor apparatus.



5. 6a. 6b. 7.

Figures 5–7. **(5)** Type I hyperextension lesion of the PIP joint. Sagittal T1-weighted MR image shows distal avulsion of the volar plate from the base of the middle phalanx and proximal displacement (arrows). **(6)** Type III hyperextension lesion (unstable fracture-dislocation) of the PIP joint. Sagittal T1-weighted **(a)** and short inversion time inversion-recovery **(b)** MR images show a fracture (solid arrow) that involves more than 40% of the articular arch of the middle phalanx with dorsal displacement of the middle phalanx. Note the normal volar plate (open arrow) attached to the bone fragment. **(7)** Volar dislocation of the PIP joint. Sagittal T1-weighted MR image shows a tear of the volar plate (thick arrow), which manifests as high signal intensity and contour irregularity. There is also a partial tear of the extensor central slip at its insertion on the base of the middle phalanx (thin arrow).

Type III lesions are characterized by a fracture-dislocation of the volar base of the middle phalanx. These lesions may be classified according to the size of the fragment and the resultant stability of the joint (14). A stable injury usually involves less than 40% of the articular surface while leaving the collateral ligaments attached to the middle phalanx. An unstable injury involves more than 40% of the articular surface with the volar plate and collateral ligaments attached to the volar fragment, thus inducing a tendency toward dorsal luxation (Fig 6).

The treatment is conservative in all cases except for unstable type III injury (fracture-dislocation), which needs open reduction and internal fixation.

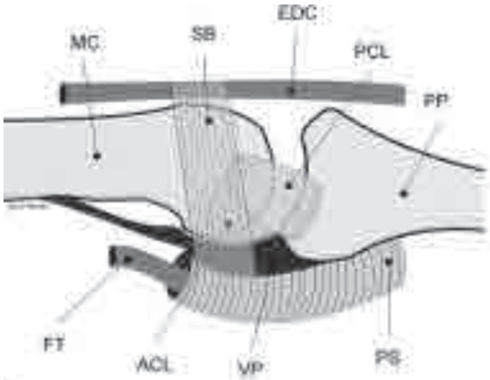
The mechanism of lesions due to compression is rotational longitudinal compression of a semiflexed PIP joint, which causes volar luxation or subluxation of the middle phalanx with unilateral disruption of the collateral ligament and at least partial avulsion of the volar plate (17). These infrequent lesions are severe due to the possible presence of an associated lesion of the extensor apparatus (Fig 7). If an additional rotational force is applied together with the longitudinal compression, one of the condyles of the proximal phalanx might become trapped in a "buttonhole" fashion between the central slip and the lateral band. Open surgical reduction is mandatory in these cases. The central slip may sometimes be avulsed. If left untreated, this injury results in chronic boutonnière deformity: flexion of the PIP joint and extension of the distal interphalangeal (DIP) joint (18).

MCP Joint

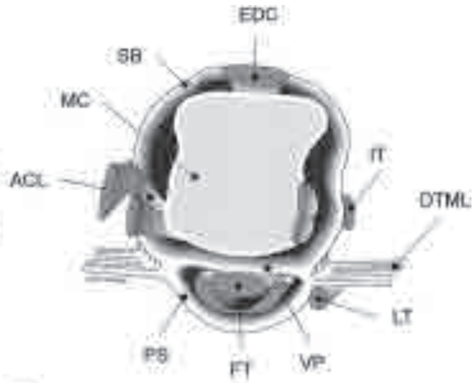
Anatomy

Although the supporting structures of the MCP joint and PIP joint are similar, the bony anatomy of the unicondylar MCP joint allows significant radial and ulnar deviation and some rotation. The collateral ligaments of the MCP joint are taut in

Figures 8, 9. Anatomy of the MCP joint. **(8)** Lateral **(a)** and axial **(b)** drawings show the accessory collateral ligament (*ACL*), deep transverse metacarpal ligament (*DTML*), extensor digitorum communis tendon (*EDC*), flexor tendons (*FT*), interosseous tendons (*IT*), lumbrical tendon (*LT*), metacarpal (*MC*), proper collateral ligament (*PCL*), proximal phalanx (*PP*), A1 pulley (*PS*), sagittal bands (*SB*), and volar plate (*VP*). **(9a)** Sagittal T2-weighted MR image shows the volar plate (arrow). *MC* = metacarpal, *PP* = proximal phalanx. **(9b, 9c)** Axial T1-weighted MR image **(b)** and photograph of an axial cross section of a cadaveric hand **(c)** show the volar plate (*), deep transverse metacarpal ligament (large solid arrows), collateral ligaments (arrowheads), sagittal bands (small solid arrows), and extensor tendon (open arrow).



8a.



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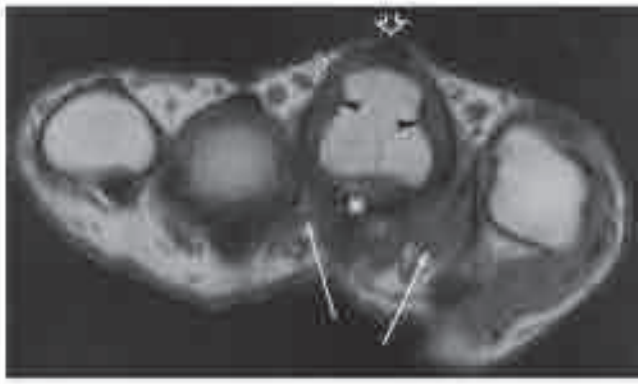
9a.



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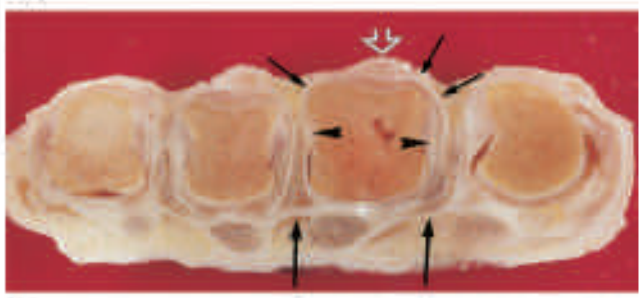


9c.

flexion and lax in extension, allowing abduction and adduction (13). The volar plate is an important stabilizer of this joint and is interconnected with the adjacent MCP joints by the deep transverse metacarpal (interglenoid) ligament. The extensor hood (particularly its sagittal bands), which stabilizes the extensor tendon at this level, also contributes to the stability of the joint (Figs 8, 9) (19).

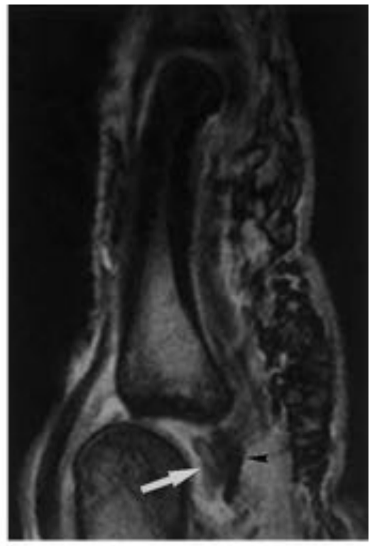
Injuries

Dislocation of the MCP joint is uncommon, but when it occurs it is usually dorsalward and follows the forced hyperextension of the finger. MCP dislocations may be simple or complex. In simple dislocations, the volar plate is not interposed in the joint and the treatment is conservative. Complex MCP dislocations may not be reduced due to the interposition of the volar plate (16). Open surgical reduction is necessary. MR imaging may be used to show the state of the volar plate and

Figures 10, 11. **(10)** Simple dislocation of the MCP joint. Sagittal T1-weighted MR image shows distal avulsion of the volar plate of the MCP joint (solid arrow). Note the normal volar plate at the PIP joint (open arrow). **(11)** Complete tear of the radial collateral ligament of the MCP joint with intraarticular interposition of the ligament. **(a)** Coronal T2-weighted MR image shows proximal complete disruption and retraction of the radial collateral ligament (arrows). **(b)** Sagittal T2-weighted MR image shows the collateral ligament (arrow) interposed between the volar plate (arrowhead) and the MCP joint. Note the volar subluxation of the proximal phalanx.

10.

11a.



11b.

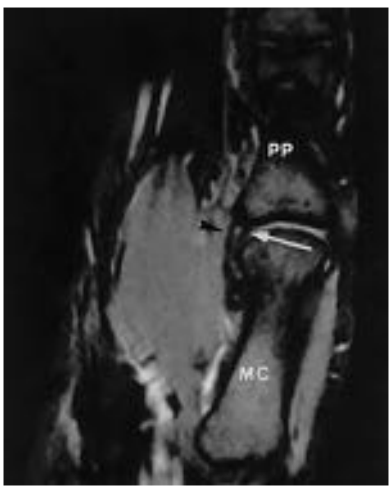


Figure 12. Normal anatomy of the UCL. Oblique coronal T2-weighted MR image shows the UCL (arrow) and overlying adductor aponeurosis (arrowhead). *MC* = metacarpal, *PP* = proximal phalanx.

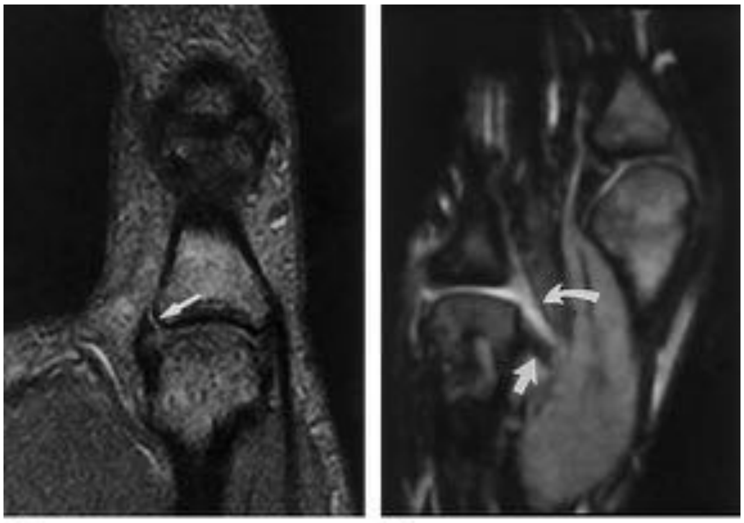
allows exact identification of its location and displacement (Fig 10). One collateral ligament may be ruptured after the dislocation and secondarily to the lateral deviation, with the MCP joint in a flexion position (16). Intraarticular interposition of the ligament is also possible (Fig 11).

Anatomy of the MCP Joint of the Thumb

The MCP joint of the thumb is a condylar-type articulation that allows motion primarily in the flexion-extension axis and also some degree of rotation. Similarly to the PIP and MCP joints of the finger, the MCP joint of the thumb is stabilized by the volar plate, collateral ligaments, and musculotendinous structures. The adductor pollicis has a strong tendinous point of insertion into the proximal phalanx and volar plate–sesamoid complex. Some of its fibers also contribute to the adductor aponeurosis, which covers the UCL (Fig 12) (20).

Gamekeeper Thumb

Injuries to the UCL of the first MCP joint are frequent. This injury is very commonly caused by skiing accidents and is also called "skier's thumb." It occurs after violent hyperabduction of the thumb. Rupture of the UCL may be total or partial and usually takes place at its distal point of insertion. It might be accompanied by bone avulsion. In total rupture of the UCL, retraction may be mild (with the torn UCL beneath the adductor aponeurosis) or severe and associated with interposition of the adductor aponeurosis (with the torn UCL lying superficially at the proximal end of the aponeurosis). The latter condition, which is called a Stener lesion (21), requires surgical treatment because conservative treatment would lead to chronic instability. Usually, the difference between a complete and an incomplete tear can be



13. 14.

Figures 13, 14. **(13)** Nondisplaced tear of the UCL. Oblique coronal T1-weighted MR image shows discontinuity of the distal portion of the UCL (arrow), which lies beneath the adductor aponeurosis. **(14)** Ruptured UCL with a Stener lesion. Oblique coronal T2-weighted MR image shows a torn UCL (straight arrow), which is retracted and lies superficial to the adductor aponeurosis (curved arrow).

discerned after physical examination. A complete tear induces the appearance of a palpable mass in the ulnar aspect of the joint and instability to radial stress reaching an angle of 30° or higher when compared with the contralateral thumb (20). Nevertheless, the difference between a nondisplaced UCL tear and a Stener lesion is not unequivocal at clinical examination (8). Moreover, the maneuvers during the clinical examination may turn a nondisplaced lesion into a displaced one.

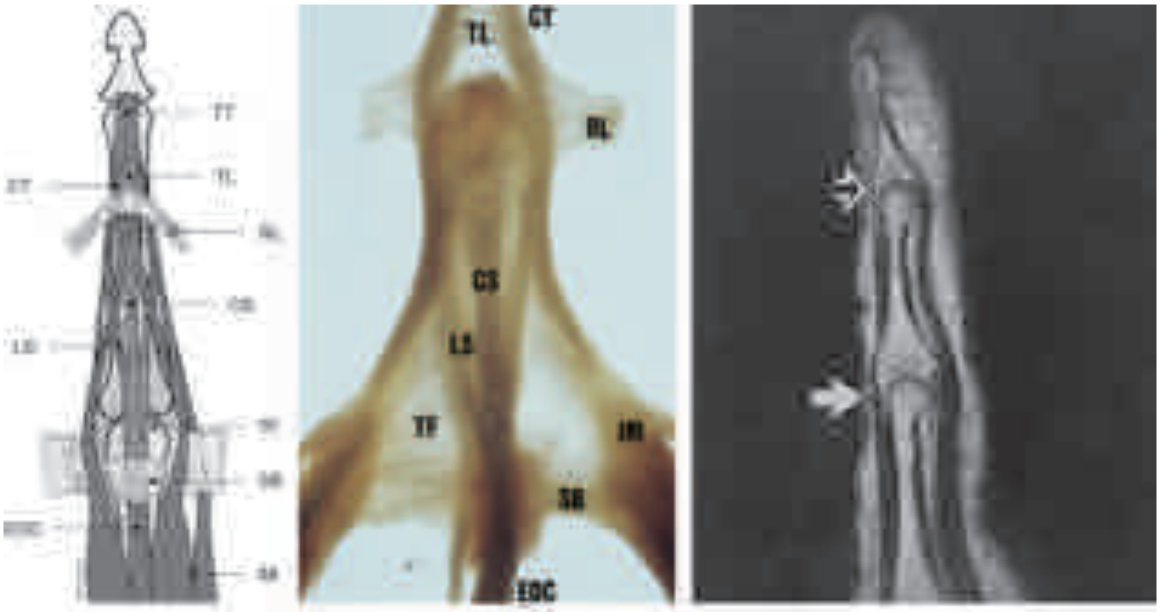
MR imaging is a sensitive technique for studying the Stener lesion (8–10,22). A nondisplaced torn UCL appears on MR images as a gap in the otherwise normally located UCL (Fig 13). The ligament usually appears to be thickened beneath the adductor aponeurosis. A displaced rupture is diagnosed when the torn UCL is displaced to the proximal margin of the adductor aponeurosis (Fig 14). The ligament usually appears as a rounded or stumplike area of low signal intensity located more superficially than a normal ligament. In the Stener lesion, the adductor aponeurosis, which normally appears as a thin hypointense structure, usually shows surrounding hyperintense effusion on T2-weighted MR images.

Extensor Tendons

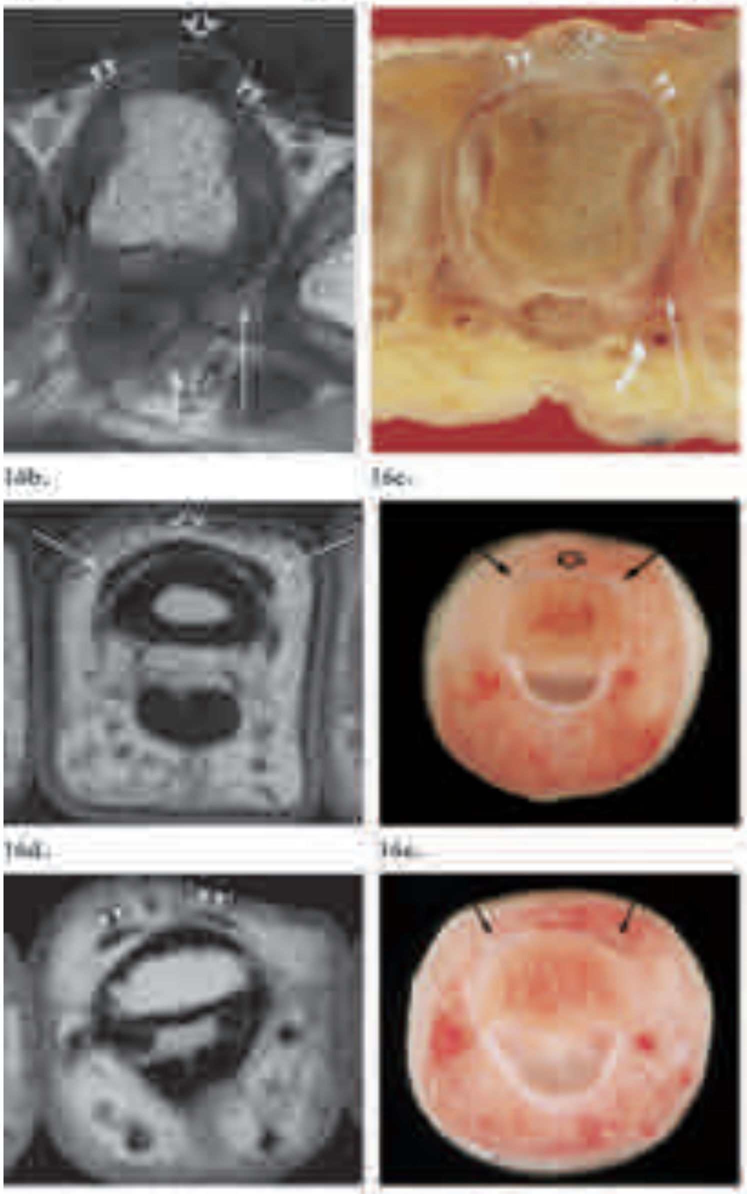
Anatomy

Digit extension involves simultaneous action of both extrinsic and intrinsic extensor muscles. Extrinsic muscles originate in the forearm and elbow and insert in the hand. These tendons are the extensor digitorum communis, extensor indicis proprius (EIP), and extensor digiti quinti minimi (EDQM). Their function is primarily extension of the MCP joint but also extension of the PIP and DIP joints (23). The EIP and EDQM tendons move independently, allowing extension of the index and small fingers through a considerable range of movements. The intrinsic muscles are the interosseous and lumbrical muscles, which originate and insert in the hand. Their function is extension of the PIP and DIP joints and flexion of the MCP joint (24).

The extensor tendons reach the hand by passing through fibro-osseous tunnels or dorsal compartments in the wrist. Near the midportion of the metacarpals, the extensor tendons are interconnected by the juncturae tendinum, which prevent independent extension of the digits (23,25). At the MCP joint, these extrinsic tendons are stabilized over the dorsum of the metacarpal head by the extensor hood (Figs 8, 15, 16). The sagittal bands are the main component of the extensor hood, which starts mainly at the volar plate and has a dorsal tendinous point of insertion, gliding with the extensor system as the digit moves. Distal to the sagittal bands, the transverse fibers of the intrinsic tendons contribute to the anatomy of the extensor hood. Distal to the MCP joint, the extrinsic and intrinsic tendons blend into the dorsal apparatus and are circumferentially distributed over the dorsum of the fingers. The extrinsic extensor tendon continues in the central and lateral slips (26) or bands (27). The central slip inserts on the base of the middle phalanx. The intrinsic tendons contribute to form the lateral slips. Moreover, they send fibers medially to form part



15a. 15b. 16a.



16b. 16c. 16d. 16e. 16f. 16g.

Figures 15, 16. Anatomy of the extensor apparatus. **(15)** Drawing (dorsal view) **(a)** and photograph of a transilluminated anatomic specimen of the extensor apparatus of the index finger **(b)** show the central slip (*CS*), conjoint tendon (*CT*), extensor digitorum communis tendon (*EDC*), intrinsic muscles (*IM*), lateral slip (*LS*), retinacular ligaments (*RL*), sagittal bands (*SB*), transverse fibers (*TF*), triangular ligament (*TL*), and terminal tendon (*TT*). **(16a)** Sagittal T1-weighted MR image shows the insertion of the central slip on the base of the middle phalanx (solid arrow) and the insertion of the terminal tendon on the base of the distal phalanx (open arrow). **(16b, 16c)** Axial T1-weighted MR image **(b)** and photograph of an axial cross section of a cadaveric finger **(c)** obtained at the MCP joint show the extensor digitorum communis tendon (open arrow), sagittal bands (arrowheads), interosseous tendon (straight solid arrow), and lumbrical tendon (curved arrow). **(16d, 16e)** Axial T1-weighted MR image **(d)** and photograph of an axial cross section of a cadaveric finger **(e)** obtained proximal to the PIP joint show the central slip (open arrow) and lateral slips (solid arrows). **(16f, 16g)** Axial T1-weighted MR image **(f)** and photograph of an axial cross section of a cadaveric finger **(g)** obtained at the middle phalanx show the conjoint tendons (arrowheads in **f**, arrows in **g**).

of the central slip. Once the lateral slips receive the contribution of the intrinsic muscles, they are called conjoint tendons and converge distally to form the terminal tendon, which inserts on the base of the distal phalanx (25). Between the conjoint tendons, the triangular ligament keeps these structures in a position that is dorsal to the rotational axis of the PIP joint. The tendons of the dorsal apparatus are also spatially and functionally connected by retinacular ligaments at the PIP joint and middle phalanx.

On MR images, the normal extensor tendons appear as thin structures of very low signal intensity in the expected locations (Fig 16). The axial and sagittal planes are the most useful for tendon identification. Stabilizing fibrous structures, especially the sagittal bands, are characterized by uniform low signal intensity, as is the case with other ligamentous or retinacular structures. These bands are best seen in axial planes.

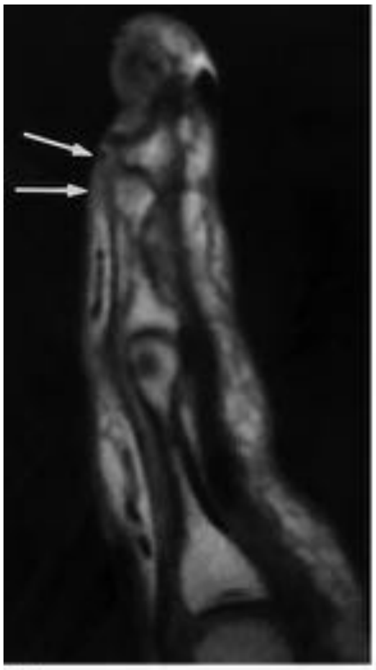
Injuries

Injuries to the extensor mechanism of the finger are common because it consists of thin, superficially located structures. These anatomic structures predispose tendons to lacerations and also to closed tendon injuries, including avulsion.

Open Injuries.—Owing to characteristic anatomic features of the extensor tendon system and to the specific findings according to its lesional topography, the concept of anatomic zones has been developed. Various classifications have been developed; the most accepted one includes eight zones (28), with zone 1 located at the DIP joint and zone 8 at the distal forearm. The odd zones correspond to the articular areas, where the extensor apparatus contains longitudinal fibers and transverse elements that maintain the apparatus in a centered position and attached to the joint. Therefore, an injury to these zones may create a lesion of the extensor apparatus and the articular structures (29). Laceration of the terminal tendon may take place in zone 1, leading to deformity of the distal phalanx in flexion (open mallet deformity) (Fig 17). Laceration of the central slip is possible in zone 3 (Fig 18), with eventual development of a boutonnière deformity secondary to flexion of the PIP joint and hyperextension of the DIP joint. In zone 5, besides lesions of the extensor digitorum communis tendon, there may be injury to the sagittal bands, which may lead to tendinous subluxation or dislocation. In the even zones, owing to the semicircular morphology of the extensor apparatus that covers the dorsal aspect of the fingers, a partial lesion is usually found (as a single wound seldom provokes a complete lesion). In total laceration, the extensor apparatus does not usually show significant retraction due to its attachment system and its connections (29,30). The extensive vascularization of the extensor apparatus predisposes to formation of adhesions from the injured tendon to adjacent tissues, such as bone or the underlying joint. These adhesions may induce important functional impairment and deformities (30). The treatment of choice is tendinous surgical suturing (27).

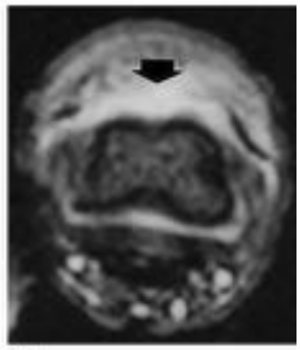
Diagnosis of a partial-thickness tear of the extensor apparatus with MR imaging is based on the presence of areas of increased signal intensity on T1-weighted (and sometimes T2-weighted) images, located within a portion of the tendon. These areas do not extend to all of the tendon. A complete tendon laceration appears as an area of discontinuity with fraying and irregularities at both ends of the ruptured tendon (Figs 17, 18). MR imaging can also depict the gap produced by the lesion, even if its extension is limited. When the laceration is acute, the tendon gap has intermediate signal intensity on T1-weighted images and high signal intensity on T2-weighted images; these findings are consistent with edema and hemorrhage. MR imaging may show the presence of adhesions as an area of blurring at the margins of the tendinous surface in association with abnormal signal intensity in the surrounding fat, together with distortion of the normal anatomy of the tendon (Fig 19).

When these open wounds are due to injury caused by metallic devices, a frequent finding is the presence of microartifacts, which appear as tiny areas of signal void (Fig 17). As in other anatomic regions, a possible "magic angle" effect can be detected when the orientation of the extensor tendons approaches an angle of 55° in relation to the direction of the B_0 magnetic field, resulting in increased intratendinous signal intensity, which may mimic pathologic changes (31).



17.

18a.



18b.

Figures 17, 18. **(17)** Complete laceration of the conjoint tendon at its distal insertion on the base of the distal phalanx. Sagittal T1-weighted MR image shows disruption of the conjoint tendon (arrows) with soft-tissue edema and hemorrhage. Flexion deformity of the distal phalanx is apparent. Note the metallic artifacts secondary to a wound. **(18)** Complete laceration of the central slip at its insertion on the base of the middle phalanx. Sagittal **(a)** and axial **(b)** T2-weighted MR images show disruption of the central slip with a hyperintense gap (arrows). This acute case was secondary to a wound. Note the absence of the classic boutonnière deformity.

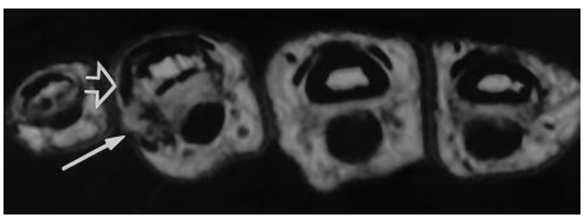


Figure 19. Adhesions of the extensor system. Axial T1-weighted MR image obtained just proximal to the PIP joint shows hypointense scar tissue (solid arrow) beside an asymmetrically swollen and volarly displaced lateral slip (open arrow), which includes adhesions secondary to a previous wound.

Closed Injuries.—Closed tendon injuries include mallet finger, boutonnière deformity, and subluxation or dislocation of the extensor tendon mechanism at the MCP joint.

A mallet finger injury results from a lesion of the bony or ligamentous attachment of the extensor mechanism to the distal phalanx. This loss of extensor continuity results in incomplete extension of the DIP joint or extensor lag. This is the most common closed tendon injury seen in sports (32). It usually occurs when the tip of the finger is struck by or against an object, resulting in acute flexion of the DIP joint (30). Mallet finger can also result from a direct blow to the dorsum of the distal DIP joint or be secondary to a hyperextension force applied at this joint (18). At clinical examination, the patient has pain and swelling at the dorsum of the DIP joint and cannot extend the joint. Presently, the treatment most commonly used is closed splinting with the DIP joint in extension (30,33). If left untreated, a mallet deformity will frequently progress to a swan-neck deformity (18). This is the result of a flexion deformity of the DIP joint together with hyperextension of the PIP joint, which is caused by retraction of the extensor mechanism.

Injuries of the terminal extensor tendon may be detected on sagittal MR images, which allow confirmation of the diagnosis in cases with no bone avulsion. The MR imaging appearance overlaps that of open mallet injuries (Fig 17).

A boutonnière deformity is the result of an injury to the central slip at or near its point of insertion on the base of the middle phalanx. Less frequently, a boutonnière deformity is associated with a fracture of the central slip attachment. Rupture of the central slip and eventual boutonnière deformity may be caused by a blow to the dorsum of the middle phalanx, acute violent flexion of the PIP joint, or volar dislocation of the PIP joint (18,30). In the early acute phase, the results of physical examination may be misleading because the lateral bands may still be in their proper anatomic position and still extend the PIP joint. Initial findings include pain and swelling of the PIP joint, a mild extension lag, and reduced extension strength against resistance. If the injury goes unrecognized, the lateral bands move volarly to the axis of rotation of the PIP joint. This induces flexion of the PIP joint and an increase in the force on the intact terminal extensor insertion, with subsequent extension of the DIP joint (34). The head of the proximal phalanx can be displaced through the defect at the level of the extensor apparatus. The deformity is not apparent during the first 7–14 days (30). Extension splinting of the PIP joint is the treatment of choice for acute boutonnière deformity. Surgical intervention is required when soft-tissue interposition prevents congruent reduction after dislocation of the PIP joint or when a large displaced bone fragment is present. Surgical reconstruction is the treatment of choice for chronic symptomatic cases (34).

MR imaging is an effective method for detecting lesions of the central slip, especially during the acute phase, when the clinical diagnosis is not unequivocal. Axial and sagittal MR images depict complete tears of the central extensor tendon as a complete disruption of the tendon fibers (Fig 20). MR imaging can provide useful information about associated volar plate and ligamentous lesions of the PIP joint, as described elsewhere.

Figure 20. Boutonnière deformity. Sagittal T1-weighted MR image shows discontinuity of the central slip at its distal insertion on the base of the middle phalanx (long arrow). A classic deformity with flexion of the PIP joint and extension of the DIP joint is seen (short arrows).

Subluxation or dislocation of the extensor digitorum communis tendon at the MCP joint occurs as a result of tearing of the sagittal bands of the extensor hood. This injury is the result of a direct blow forcing the finger into flexion or of forced flexion and ulnar deviation of the finger (18). Ulnar subluxation is more common and usually affects the middle finger. Radial subluxation is unusual but can occur with forced valgus injury (7). At clinical examination, the patient has pain and swelling over the MCP joint. There is usually an inability to completely extend the MCP joint. In chronic untreated cases, the patient has a history of multiple episodes of pain and swelling over the MPC joint with a snapping sensation in the finger. If the injury is in its acute phase, conservative treatment with splinting of the MCP joint in extension is recommended (35). Surgical correction is necessary in chronic symptomatic cases (36).

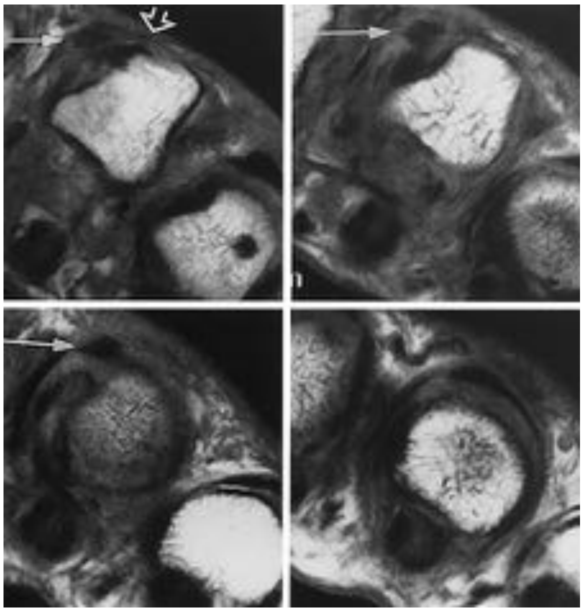


Figure 21. Radial dislocation of the extensor digitorum communis tendon at the MCP joint. Consecutive axial T1-weighted MR images show radial subluxation of the extensor digitorum communis tendon (solid arrows) with a normal central position at the distal level (bottom right image). Note the lack of visualization or poor definition of the cubital sagittal band (open arrow), which suggests a chronic tear.

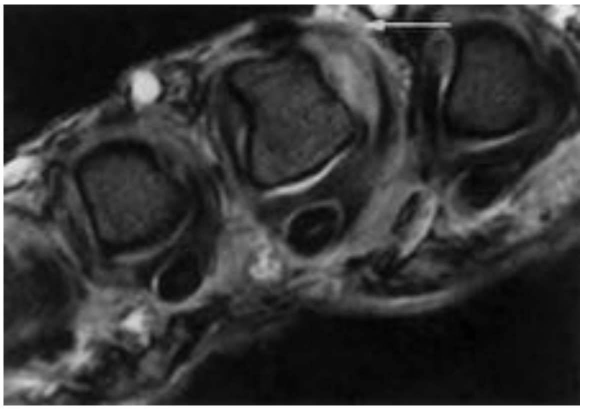


Figure 22. Partial tear of the radial sagittal band of the middle finger. Axial T2-weighted MR image shows increased signal intensity and poor definition of the radial sagittal band (arrow) near the extensor digitorum communis tendon.

MR imaging allows direct assessment of the position of the tendon relative to the metacarpal head. Dislocation is best depicted on axial images (Fig 21). MR imaging is also useful in evaluation of extensor hood injuries (7). In acute cases, the findings include morphologic and signal intensity abnormalities within and around the extensor hood components (particularly the sagittal bands) on axial T1- and T2-weighted images, together with poor definition, focal discontinuity, and focal thickening (Fig 22).

Flexor Tendons

Anatomy

The digital flexor tendons pass through the carpal tunnel before spreading out in the palm toward their respective fingers. Each finger has two flexor tendons: the flexor digitorum superficialis (FDS), which inserts on the midportion of the middle phalanx, and the flexor digitorum profundus (FDP), which lies volar to the FDS and inserts on the volar base of the distal phalanx (Fig 23). The FDS tendon splits at the distal metacarpal, passes around the FDP tendon, and reunites deep to the FDP tendon at the level of the PIP joint. Thus, the FDS tendon forms a ring aperture through which the FDP tendon passes to become the superficial tendon at the level of the shaft of the proximal phalanx.

From the neck of the metacarpal to the DIP joint, the flexor tendons run along osteofibrous canals lined by a synovial sheath that provide nutrition and lubrication to the tendons. The flexor tendons are connected to the synovial sheath by the vincula, which contain the blood supply to the tendons (37). The floor of the fibro-osseous canal is the volar aspect of the phalanges and the volar plates of the MCP and interphalangeal joints. The fibrous portion of the canal consists of five annular pulleys (A1–A5), which are transverse, well-defined areas of thickening of the tendon sheath, and three cruciform pulleys (C1–C3), which are formed by crisscrossing fibers of the components of the annular pulley (Fig 23) (38,39).

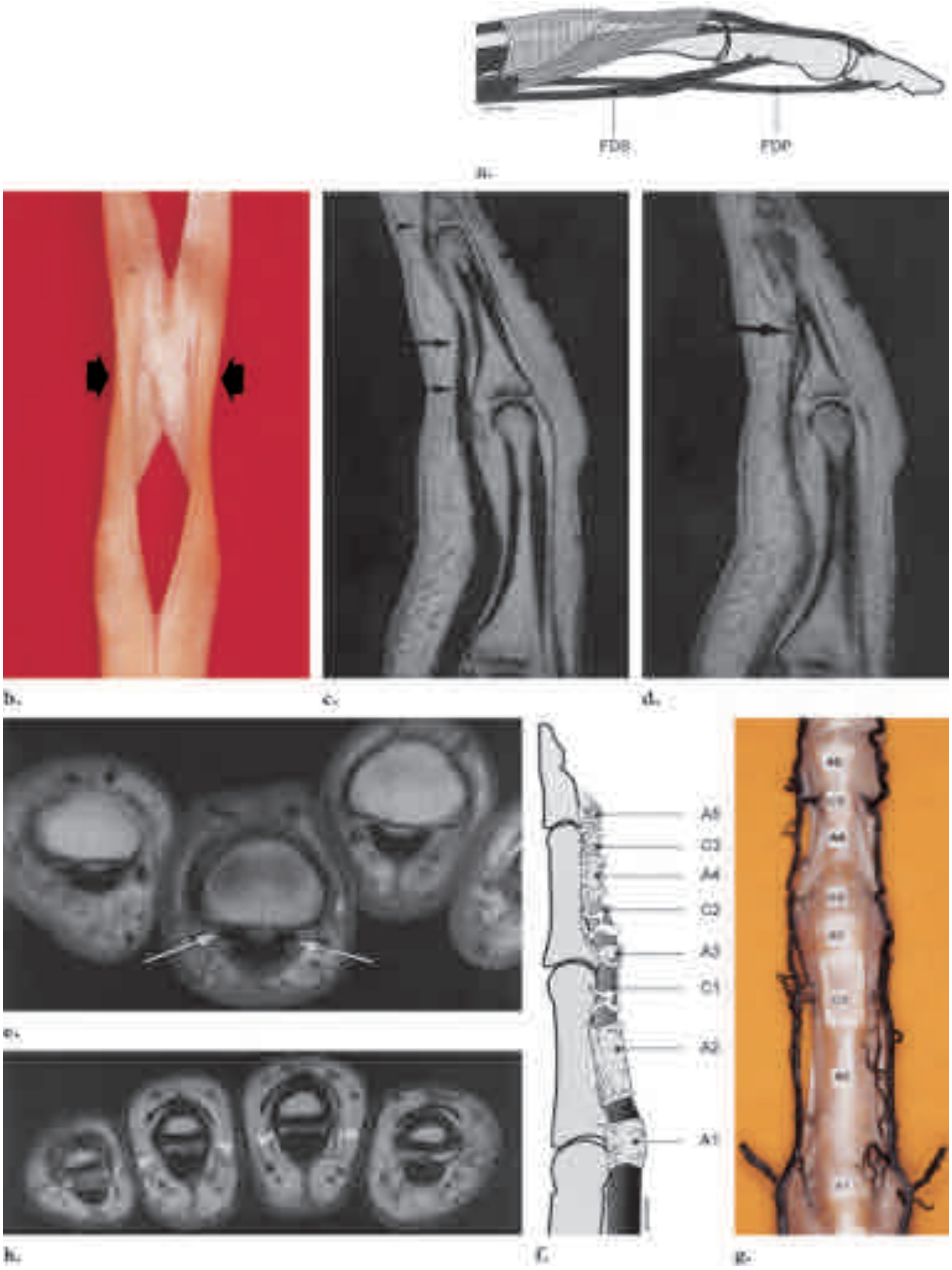


Figure 23. Anatomy of the flexor tendons. **(a)** Drawing (lateral view) shows the FDP and FDS tendons and their points of insertion. **(b)** Photograph of a dissected anatomic specimen shows a superficial volar view of the chiasm of the FDS tendon. The FDP tendon is not present. Note the joining of the two slips (arrows) before their final individual insertions on the middle phalanx. **(c)** Midsagittal T1-weighted MR image shows the FDP tendon (arrows) and its insertion on the base of the distal phalanx (arrowhead). **(d)** Parasagittal T1-weighted MR image shows the insertion of the FDS tendon on the middle phalanx (arrow). **(e)** Axial T1-weighted MR image obtained distal to the PIP joint shows the two slips of the FDS tendon immediately before their insertion (arrows). **(f)** Drawing (lateral view) shows the pulley system: annular pulleys (A1–A5) and cruciate pulleys (C1–C3). **(g)** Photograph of a dissected anatomic specimen shows a palmar view of the pulley system: annular pulleys (A1–A5) and cruciate pulleys (C1–C3). **(h)** Axial T1-weighted MR image shows the A2 pulleys (arrowheads).

The first annular pulley (A1) begins in the palmar plate of the MCP joint and extends to the base of the proximal phalanx. The second annular pulley (A2) rises from the volar aspect of the proximal portion of the proximal phalanx and extends to the distal third of the proximal phalanx. The third annular pulley (A3) is small and extends over the region of the PIP joint. The fourth annular pulley (A4) lies in the midportion of the middle phalanx, whereas the fifth annular pulley (A5) is located in the region of the DIP joint. The A2 and A4 pulleys are the largest and thickest and also have the most constant morphology and prevalence. The cruciform pulleys are the most variable in shape and prevalence. The first (C1) and third (C3) cruciform pulleys often blend at the distal end of the A2 and A4 pulleys, respectively. The main function of the annular pulleys is to fix the tendon sheaths to the bony skeleton, thus stabilizing the tendon during finger flexion and avoiding palmar "bowstringing." The cruciform pulleys are designed to permit deformation of the tendon sheath during flexion without impingement of the tendon itself (39).

The flexor tendons are well visualized as low-signal-intensity structures, thicker than extensor tendons, with all MR imaging pulse sequences. In general, T1-weighted images provide good anatomic detail whereas T2-weighted images are useful in assessment of an abnormal water increase, which is associated with most pathologic conditions.

Injuries

Injuries to the flexor tendons are not as common as injuries to the extensor apparatus. As with extensor tendon injuries, we can divide the lesions into two groups: open injuries and closed injuries. Injuries of the pulley system are also described.

Open Injuries.—Flexor tendon lacerations associated with skin wounds are more common than closed traumatic ruptures. They rarely occur at the point of bony insertion of a normal tendon; instead, they often affect the midsubstance (40). As with the extensor tendon apparatus, a division of the flexor tendons into multiple zones has been established based on the distinct anatomic differences responsible for different prognoses of otherwise identical tendon injuries (28). The flexor tendons are divided into five zones. Zone I extends from the distal insertion of the FDP tendon to the distal insertion of the FDS tendon. Zone II (the so-called no-man's-land) extends from the distal insertion of the FDS tendon to the distal palmar fold, with the FDP and FDS tendons in direct contact. Lacerations in zone II are the most frequent and carry the most severe prognosis (41). Zone III extends from the proximal part of the A1 pulley to the distal part of the flexor retinaculum. Zones IV and V consist of the carpal tunnel and the forearm proximal to the flexor retinaculum, respectively. Zone I injuries are isolated lacerations of the FDP and manifest clinically as loss of active flexion of the distal phalanx. Trauma in the four proximal zones is associated with lesions of both flexor tendons and implies the loss of active flexion of the PIP and DIP joints. In addition, injuries to the major neurovascular structures have been reported.

As in the extensor tendons, the injuries may be partial or complete. Clinical diagnosis of partial lacerations is difficult because the physical signs are nonspecific. Clinical diagnosis may be easy in complete lacerations, but assessment of the degree of proximal retraction of the tendon may be difficult, as the tendon can sometimes be displaced as far as the palmar fold. Surgical repair is the treatment of choice for complete lacerations. The treatment for partial tendon lacerations remains controversial, and conservative treatment is recommended in several cases (42).

MR imaging has been successfully used to diagnose tendon disruption and to accurately visualize the locations of the ends of the lacerated tendon (3,4,6,43,44). This technique may also provide additional information about the degree of injury, thus allowing differentiation of partial and

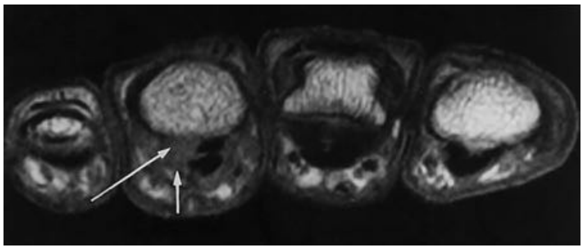


Figure 24. Partial tear of the FDP tendon. Axial T1-weighted MR image of the MCP joint shows heterogeneous signal intensity in approximately half of the fibers of the FDP tendon (short arrow). Note that the medial slip of the FDS tendon is completely disrupted (long arrow).

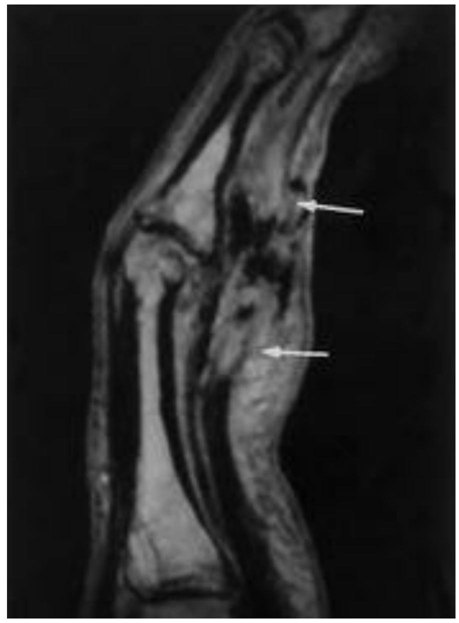


Figure 25. Complete laceration of the FDP tendon. Sagittal T1-weighted MR image clearly shows a laceration of the FDP tendon and the gap between the tendon ends (arrows). Note the metallic artifacts secondary to an open wound.

complete lacerations (Figs 24, 25) (5). The MR imaging findings in flexor tendon injuries are similar to those described for the extensor tendons. Nevertheless, the lack of a stronger fixation system, such as that existing in the extensor apparatus, implies that a higher degree of retraction may appear in some lacerations. In these cases, the real gap may be overestimated when the tendon is curled and remains flexible. Associated MR imaging findings include tenosynovitis, luxation of the injured tendon, and disruption of the pulley system.

Closed Injuries.—Closed tendon injuries include avulsion of the FDP tendon and avulsion of the FDS tendon.

Avulsion of the FDP tendon is the most frequent type of closed rupture of this tendon. It is caused by sudden hyperextension during active flexion and is most common in young males involved in sports. The mechanism of injury is the reason why this lesion is called "sweater finger" or "jersey finger" (45). The FDP tendon of the ring finger is most commonly injured. Several hypotheses for this tendency have been suggested, such as involvement of lumbrical insertions, a lower level of rupture, and the predominance of this finger in the grasp mechanism (40). This injury is often missed in the acute phase. There is no classic deformity, and swelling and pain may mask the pathognomonic sign of loss of active flexion at the DIP joint. This injury is divided into four main types according to the level of the lesion, the degree of retraction, and the absence or presence of a bone fragment. Type I lesions are characterized by retraction of the tendon into the palm. In type II lesions, the tendon retracts to the PIP joint. Occasionally, a small bone fleck is avulsed, and this can be seen at the level of the PIP joint. In type III lesions, there is avulsion of a large bone fragment, which stays in place by the A4 pulley. Type IV lesions are type III lesions associated with simultaneous avulsion of the FDP tendon from the fracture fragment. Primary repair of the tendon is the therapy of choice for most cases. Transosseous reinsertion of the tendon could be performed, even with a large gap (46). MR imaging may show the distal end of the retracted tendon, even several centimeters from its insertion (Fig 26).

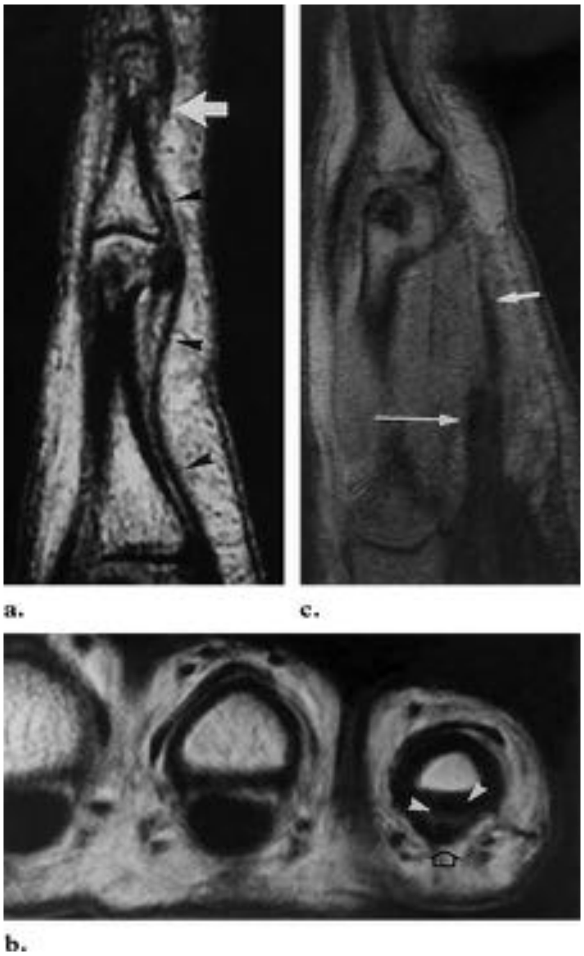


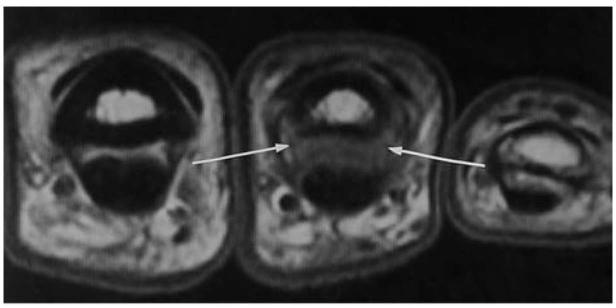
Figure 26. Distal avulsion of the FDP tendon of the ring finger. **(a)** Sagittal T1-weighted MR image shows a discontinuous distal FDP tendon (arrow). The FDS tendon is preserved (arrowheads). **(b)** Axial T1-weighted MR image shows absence of the FDP tendon in the digital canal (arrowheads). Only the two bands of the FDS tendon are shown (arrow). **(c)** Sagittal T1-weighted MR image shows the retracted FDP tendon at the proximal part of the metacarpal (long arrow). This appearance indicates a type I injury. The FDS tendon is only partially visible in this section (short arrow).

Isolated avulsion of the FDS tendon is a rare injury; most reported cases are associated with an FDP tendon injury (40). This tendon rupture occurs when the digits are forced into extension against a contracted flexor muscle. The diagnosis can be made during physical examination with the affected digit unable to flex independently at the PIP joint. MR imaging easily allows diagnosis and demonstrates the location of the distal end of the retracted tendon.

Pulley System Injuries.—Lesions of the pulley system are recognized with increasing frequency due to the growing popularity of activities, such as rock climbing, that impose extensive stress on the supporting structures of the hand and fingers (47). Powerful flexion of the fingers with MCP joint extension, PIP joint flexion, and DIP joint extension can lead to extensive forces on the A2 and A3 pulleys, with consequent ruptures. Injury of the pulley system begins at the distal part of the A2 pulley, the most important component in flexor tendon function, and progresses from partial to complete rupture, which is followed by involvement of the A3, A4, and rarely A1 pulleys (48). Disruption of the pulley system may be difficult to diagnose. The pain and swelling associated with acute injuries prevent complete evaluation of flexor tendon bowstringing. Factors that may affect the choice of treatment include the age of the patient, the degree of injury, and the number of pulleys involved. Early diagnosis and accurate assessment of the degree of digital annular pulley tear are essential for choosing between conservative treatment and surgery and can prevent both fibrous sequelae and flexion contracture of the PIP joint (49).

MR imaging has proved successful in establishing the diagnosis of isolated disruption of the pulley system, both by means of direct visualization and by demonstrating useful indirect signs. In addition, MR imaging has been used to show the extent of the lesion and to determine adequate treatment (50). Lesions of the pulley system can be diagnosed indirectly by detection of a gap between the flexor tendon and the bone on sagittal images obtained during forced flexion, a finding referred to as the "bowstringing sign" (Fig 27) (11,50). This displacement is maximal at the proximal phalanx and middle phalanx when there

Figure 27. Complete pulley rupture. Sagittal T2-weighted MR image obtained during flexion shows an increased gap between the flexor tendons and the bone (arrows), which indicates complete disruption of the A2 pulley.



a.

b.

Figure 28. Partial pulley rupture in the ring finger. **(a)** Axial T1-weighted MR image shows thickening and increased signal intensity of the A2 pulley (arrows). **(b)** Sagittal T2-weighted MR image shows no significant gap between the bone and tendon (arrows).

are tears in the A2 and A4 pulleys, respectively. Owing to the anatomy, incomplete disruption of the A2 pulley is diagnosed on sagittal MR images when bowstringing does not extend proximally beyond the base of the proximal phalanx. Conversely, proximal extension of bowstringing beyond the base of the proximal phalanx is indicative of a complete disruption. Other authors have reported that the size of the tendinous gap during forced flexion increases proportionally with the number of disrupted pulleys. This gap varies from 2–5 mm for isolated complete lesions to 5–8 mm for simultaneous complete lesions of multiple pulleys. Measurement of the tendinous gap has no significance in partial ruptures (Fig 28) (12). With the development of more dedicated surface receiver coils, identification of normal A2 and A4 pulleys is possible, thus allowing detection of signs of rupture with direct visualization of disrupted pulleys in axial sections (Fig 28). This might be helpful in current practice because it would reduce motion artifacts associated with forced flexion, which currently represent one of the most important limitations of MR imaging in detection of pulley lesions.

Conclusions

The use of dedicated surface coils has made MR imaging into a useful tool for the fine depiction of finger anatomy, owing to its high spatial resolution and its sensitivity to contrast differences within soft-tissue structures.

MR imaging allows optimal detection and evaluation of most soft-tissue lesions in the traumatic finger, including injuries to the volar plate, collateral ligaments, extensor system, flexor tendons, and pulley system. In most acute injuries, MR imaging allows precise assessment of the degree and extent of the lesion, with a remarkable effect on the therapeutic plan in individual cases. In chronic lesions, which usually manifest as finger deformities, MR imaging allows determination of the different underlying pathologic changes that affect soft-tissue articular structures, tendinous structures, or both.

Acknowledgment: The authors thank Massimo Feliciani, MD, for his help in the preparation of the manuscript.

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