MR and CT Arthrography of the Wrist

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Semin Musculoskelet Radiol 2012;16:27–41.

Abstract

The study of the wrist represents a major diagnostic challenge because of its complex anatomy and the small size of individual structures. Recent advances in imaging techniques have increased our diagnostic capabilities. However, 3T magnets, multichannel specific wrist coils, and new MRI sequences have not restricted the indications of arthrographic imaging techniques (CT arthrography and MR arthrography). Distension of the different wrist compartments at CT arthrography and MR arthrography significantly improves the diagnostic accuracy for triangular fibrocartilage (TFC) complex injuries and carpal instability. Dedicated multichannel wrist coils are essential for an adequate study of the wrist, but the placement of these coils and the positioning of the wrist are also important for proper diagnosis. The development of dynamic multislice CT studies allows a diagnostic approach that combines dynamic information and the accurate assessment of ligaments and the TFC complex. New advances in arthroscopy have changed the anatomical description of the TFC with a functional division in the proximal and distal TFC complex, and they have allowed a better characterization of lesions of the TFC complex with subclassification of Palmer 1B and 1D lesions and description of new lesions not included in the Palmer classification, such as capsular injuries.

Keywords

- triangular fibrocartilage
- arthrography
- MR arthrography
- CT arthrography
- wrist
- ulnar impaction
- carpal instability

Technique

Intra-articular injection of a contrast agent is generally performed under fluoroscopic guidance; nevertheless, sonographic, CT, or MR guidance may be also used.[1]

Multiple sites can be chosen to successfully distend the carpal joints[1] (►**Fig. 1**). Placement of the needle at the midpoint of the distal radioulnar joint (DRUJ) space likely will result in an extra-articular injection as often as an intra-articular one. Therefore, the needle tip should be directed to the head of the ulna near its radial margin. After the needle touches the ulnar head, it should slide slightly more radially to advance deeper into the joint space and stabilize the needle.[1] It is important that the injected contrast profile the fovea at the base of the ulnar styloid to establish if there is a defect in the ulnar attachment of the triangular fibrocartilage (TFC). Injection sites for the midcarpal compartment include the distal scaphocapitate and triquetrohamate

Issue Theme Current Concepts in MR and CT Arthrography; Guest Editor, Ara Kassarjian, M.D., F.R.C.P.C.

DOI http://dx.doi.org/10.1055/s-0032-1304299.
ISSN 1089-7860.

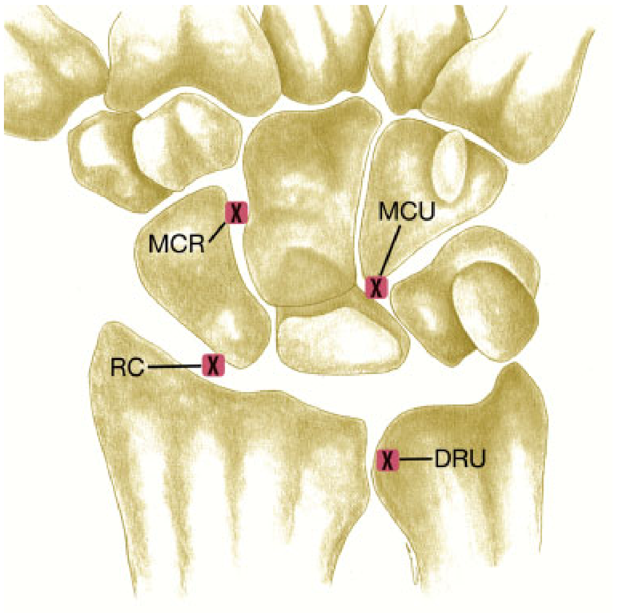

Figure 1 Diagram illustrates the injection sites for wrist joint CT/MR arthrography. RC, radiocarpal site; MCR, midcarpal radial site; MCU, midcarpal ulnar site; DRU, distal radioulnar joint site.

spaces.[1] Injection should continue until contrast is visualized readily in the capitolunate joint space. In normal arthrograms, contrast flows into both the scapholunate (SL) and lunotriquetral (LT) spaces. The intrinsic ligaments at the proximal margins of these bones arrest the proximal flow of contrast, preventing communication with the radiocarpal compartment. For radiocarpal injections, the needle should be directed into the radioscaphoid space away from the SL joint. Because of the natural volar tilt of the distal radius, slight angulation of the imaging intensifier in the cranial direction facilitates better profiling of the radioscaphoid space. This prevents the needle tip from striking the dorsal lip of the radius, which frequently overlies the radioscaphoid space on a true posteroanterior projection. The radiocarpal joint communicates with pisotriquetral joint in 34 to 70% of patients.

We usually perform triple compartment wrist arthrography with fluoroscopic guidance using the following technique. First, we inject 1 ml of the contrast solution in the DRUJ to evaluate the TFC complex. Palmer class 1B lesion is one of the main indications of CT/MR arthrography because it can precisely detect partial and complete tears of the ulnar attachment of the TFC complex. Partial foveal injuries without communication with the radiocarpal compartment are a challenging diagnosis. These types of injuries are frequently misdiagnosed on conventional MR[2] and at radiocarpal MR arthrography. Partial noncommunicating tears affecting the foveal ulnar attachment can only be adequately diagnosed with distal radioulnar joint CT/MR arthrography. Then we inject a total volume of 3 to 4 mL of the solution the midcarpal joint.[1] If no communication with the radiocarpal joint is present, a total amount of 3 mL of the diluted contrast is then injected into the radiocarpal joint.

The use of dedicated wrist coils at the patient's side vertically oriented makes the accurate diagnosis of Palmer class 1B lesions very difficult because when the wrist is in supination, the styloid process is dorsally located, producing anatomical distortion (slack) of the TFC complex ulnar attachment. With the wrist coil horizontally oriented the wrist is in a nearly neutral position and the evaluation of the ulnar insertion of the TFC complex is more accurate.[2]

TFC Complex

Injuries of the TFC complex are a recognized cause of ulnar wrist pain. The TFC complex has an important role in the stability between the ulnocarpal and the DRUJ, and in the distribution of load during wrist motion and forearm rotation.[1,3–6]

Anatomy

The TFC complex is a three-dimensional structure that can be divided in two main portions: proximal and distal. The proximal portion of the TFC complex arises from the lunate fossa of the radius, courses toward the ulnar head, and inserts in the fovea and at the base of the ulnar styloid process. It has two components: the radioulnar ligaments and the TFC (►**Figs. 2A, B**) . The distal portion of the TFC complex crosses from the ulna to the carpus and also has two components: the volar ulnocarpal ligaments and the ulnar collateral ligament complex (UCLC) or functional ulnar collateral ligament.[3] Tears of the proximal portion are associated with DRUJ instability; those of the distal portion may produce subluxation of the ulnar carpus but DRUJ stability is not affected.[7–11]

Proximal Portion of the TFC Complex

The articular disc, called the TFC, has the role of distributing compressive forces at the ulnocarpal joint. The TFC lies in the axial plane and has a triangular shape, with the base on the radial side and the vertex on the ulnar side. The radioulnar ligaments (RULs) are transverse bands that arise from the fovea and styloid of the ulna and, after coalescing, bifurcate dorsally (DRUL) and volarly (VRUL) covering the TFC, to finally insert in the very dorsal and palmar edge of the sigmoid notch of the radius with Sharpey's fibers connection.[3] At the radial insertion of the TFC complex, connection from the articular cartilage of the radius to the TFC is weaker than the peripheral ligament-bone strong connection, so that the central portion is more prone to rupture. However, radial TFC complex tears are only associated with DRUJ instability when there is peripheral involvement (rupture of one or both RULs). At the ulnar insertion, the apex of the TFC is covered by fibers of the DRUL and the VRUL, which interdigitate to form a conjoined ligament with two laminae of striated appearance. The proximal lamina attaches to the fovea of the ulna (foveal insertion), and the distal lamina attaches somewhat variably at the base or tip of the ulnar styloid (styloid insertion). The space between the proximal and distal lamina is known as the ligamentum subcruentum and should not be misinterpreted as a tear. Recent works suggest that DRUJ instability may be caused by ulnar detachment of the TFC complex, with the

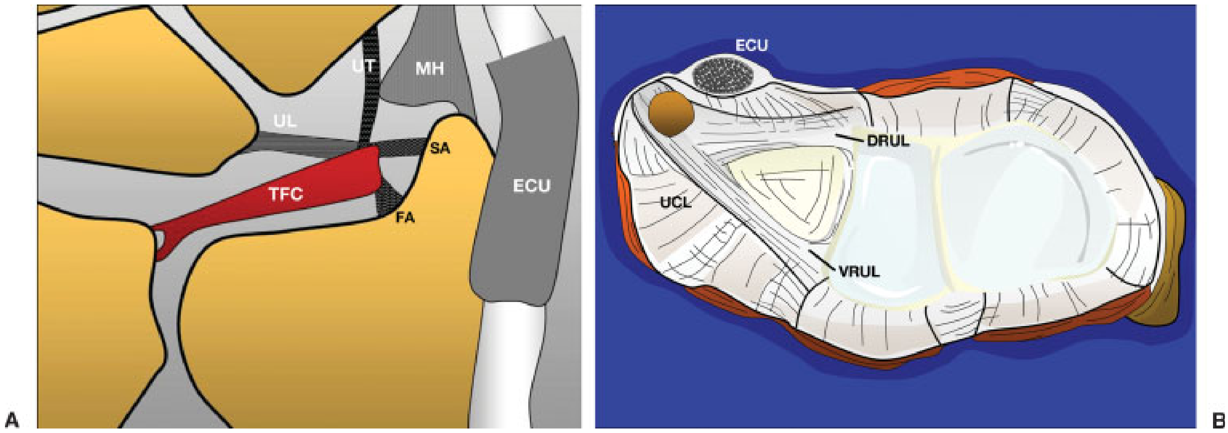

Figure 2 (A, B) Anatomy of the triangular fibrocartilage (TFC) complex. Schematic drawing of the TFC complex. TFC complex is composed of the TFC proper, the meniscus homologue (MH), the ulnar collateral ligament (UCL), the dorsal and volar radioulnar ligaments (DRUL, VRUL), the subsheath of the extensor carpi ulnaris tendon (ECU) or infratendinous extensor retinaculum, and the ulnocarpal ligaments (UCL). UL, ulnolunate ligament; UT, ulnotriquetral ligament; FA, foveal attachment; SA, styloid attachment.

foveal insertion having a greater effect on stability than the styloid insertion.[12–22]

Distal Portion of the TFC Complex

The volar ulnocarpal ligament (VUCL) arises from the fovea ulnaris (together with RUL) and extends with divergent directions to the carpal bones (triquetrum and lunate), providing stability to the ulnocarpal joint (►**Fig. 2B**). The UCLC, or functional ulnar collateral ligament, is formed by the meniscus homologue (MH), the ulnar collateral ligament, and the sheath of the extensor carpi ulnaris (ECU). The MH arises at the dorsal edge of the radial notch, and extends superficially adhered to the DRUL, giving its collateral component (the main body of the MH), which from the ulnar styloid extends deeply attached to the sheath of the ECU, to insert into the dorsoulnar side of the triquetrum. The prestyloid recess is a pit between the apex of the TFC and meniscus homologue. The MH is made of synovial tissue, which can be easily elongated and folded, so its function is to absorb the deformity that occurs in the TFC complex during wrist motion and forearm rotation.[5,22,23]

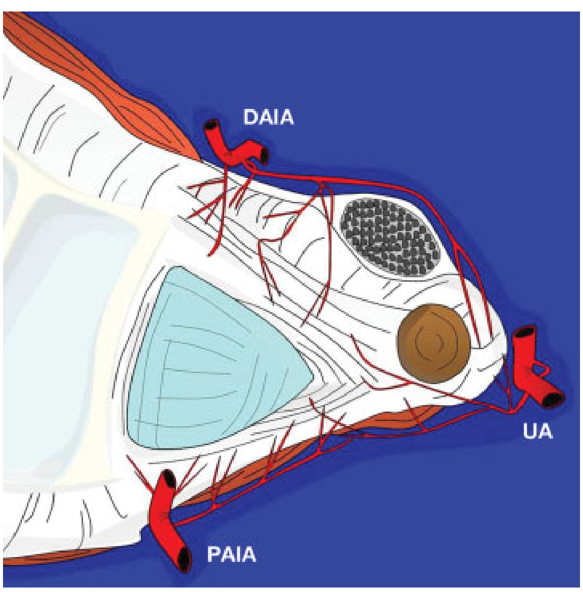

Figure 3 Diagram illustrates the vascular supply of the triangular fibrocartilage (TFC) complex. Three main arterial branches supply the TFC complex: the ulnar artery (UA), the palmar branch of the anterior interosseous artery (PAIA), and the dorsal branch of the anterior interosseous artery (DAIA). These vessels supply blood to the periphery (10 to 40%) of the TFC complex, and the central and radial portions are avascular. This pattern of supply has direct implications for the healing potential following injury.

Blood Supply of the TFC Complex

Three main arterial branches supply the TFC complex: the ulnar artery, and both the palmar and dorsal branches of the anterior interosseous artery (►**Fig. 3**). As in the meniscus of the knee, these vessels supply blood to the periphery (10 to 40%) of the TFC complex, and the central portion is avascular. In addition, no vessels cross the radial attachment to enter the TFC complex. This peripheral blood supply, in all probability, allows peripheral tears of the TFC complex to mount a reparative response, whereas the avascularity of the central portion of the TFC complex renders the articular disc unable to repair or heal. Treatment is partially guided by knowledge of this vascular anatomy.[1,5,22]

TFC Complex Injuries

Palmer devised a classification system to guide treatment of TFC complex tears in 1989.[6] The main division is between traumatic (class I) and degenerative (class II) tears (►**Table 1**).

Traumatic Tears of TFC Complex

Traumatic injuries are subdivided into four types based on the site of injury (►**Fig. 4**): class IA (Avascular disc central slit), class IB (Base of the ulnar styloid avulsion), class IC (Carpal avulsion), and Class ID (ra“D”ial avulsion). Class IA and IC tears are not associated with DRUJ instability. Class IB and ID injuries have been recently subdivided according to the different structures that can be detached from the ulnar or radial insertion of the TFCC and its relationship to DRUJ instability. TFC complex tears can be further subdivided by

Table 1 Palmer Classification Scheme for Triangular Fibrocartilage Complex Injuries

Class or Subclass	Description
Class 1	Traumatic injury
1A	Central slit
1B	Ulnar avulsion with or without distalulnar fracture
1C	Distal avulsion (carpal attachment)
1D	Radial avulsion with or without sigmoidnotch fracture
Class 2	Degenerativeinjury
2A	TFC complex wear
2B	TFC complex wear, lunate or ulnarchondromalacia
2C	TFC complex perforation, lunate orulnar chondromalacia
2D	TFC complex perforation, lunate orulnar chondromalacia, lunotriquetral ligament tear
2E	TFC complex perforation, lunate orulnar chondromalacia, lunotriquetral ligament tear, ulnocarpal osteoarthritis

TFC, triangular fibrocartilage.

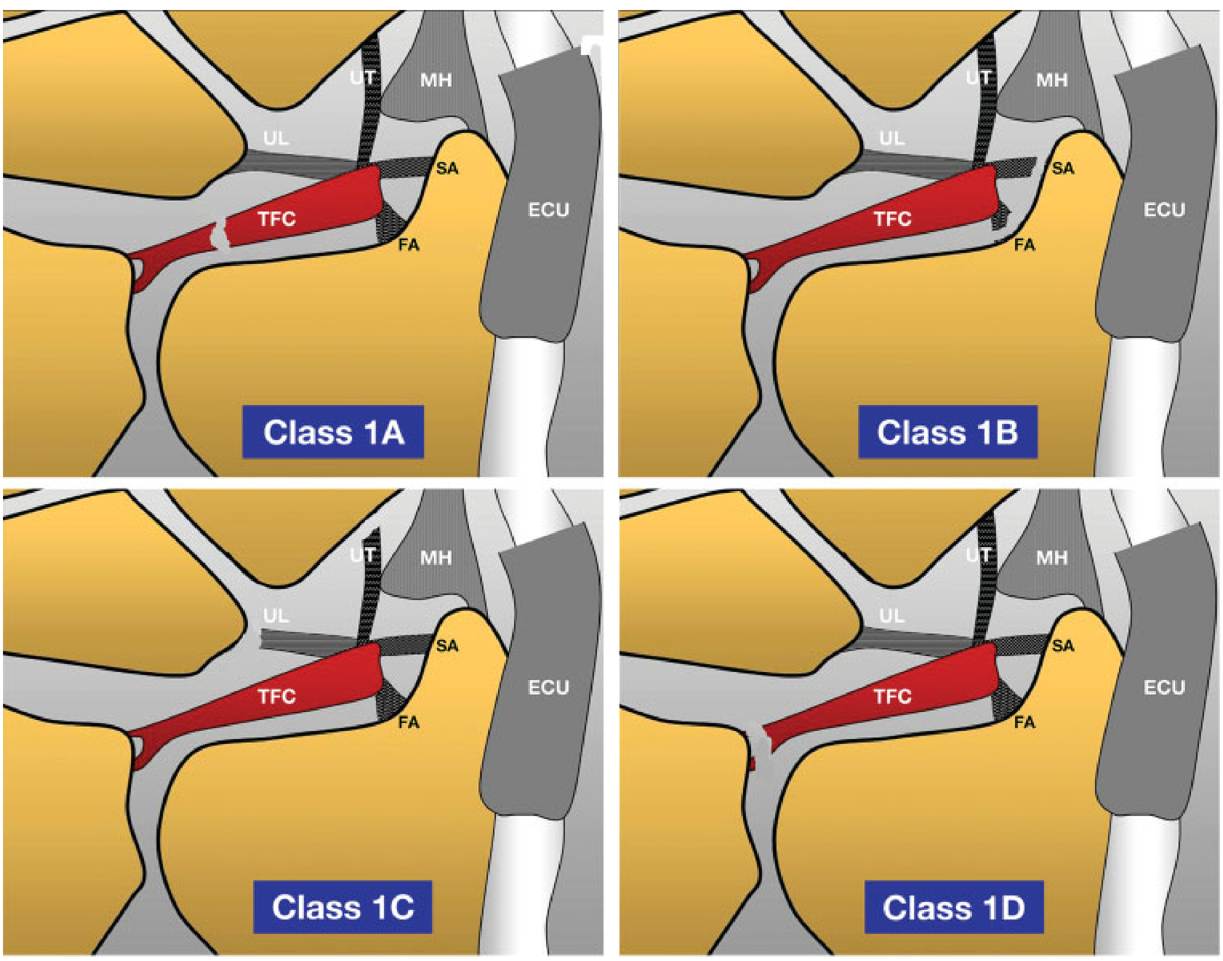

Figure 4 (A–D) Triangular fibrocartilage (TFC) complex traumatic tears Palmer class1 injuries. Type 1 traumatic injuries are also subdivided based on anatomical location into type 1A radial side central tears, type 1B ulnar side rupture with or without ulnar styloid fracture, type 1C ulnocarpal ligaments rupture, and type 1D radial avulsion of the TFC. ECU, extensor carpi ulnaris; MH, meniscus homologue; UL, ulnolunate ligament; UT, ulnotriquetral ligament; FA, foveal attachment; SA, styloid attachment.

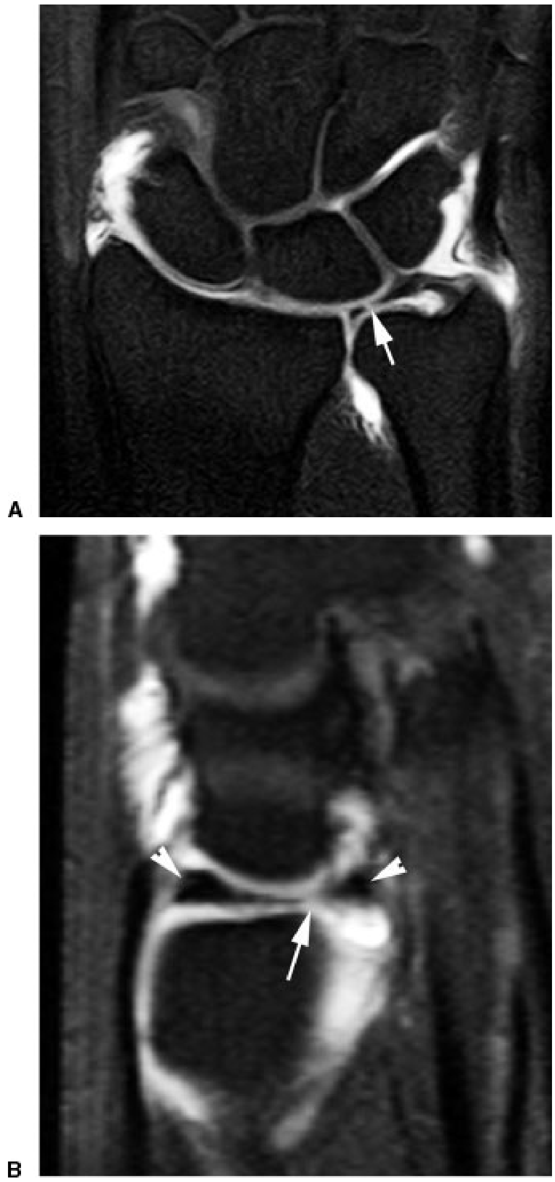

Figure 5 (A, B) Palmer class 1A traumatic tear of the triangular fibrocartilage (TFC) complex. Coronal and sagittal fat-suppressed T1-weighted distal radioulnar joint (DRUJ) MR arthrogram images show a small radial side central slit of the TFC (arrows), respecting both the distal radioulnar ligament (DRUL) and volar radioulnar ligament (VRUL) (B, arrowheads).

their acuity. Acute tears are from 0 to 3 months, subacute tears are 3 months to 1 year, and chronic tears typically present with >1 year of symptoms. The chronicity has prognostic implications; generally, addressing tears in the acute phase provides better results.[12–22]

Palmer class 1A and 1B lesions are by far the most common types of TFC complex injuries. Class 1C injuries are much less frequent, and class 1D injuries are exceptional. Moreover, we must take into account the existence of traumatic TFC complex lesions not included in the Palmer's classification, such as volar or dorsal RUL detachment from the capsule, and the avulsion of the dorsal capsule or meniscus homologue from the insertion in the dorsal aspect of the triquetrum, an injury called an ulnar detachment or Nishikawa lesion.[24]

Traumatic Tears Without Distal Radioulnar Joint Instability

Class IA (Central Avascular Disc Tear)

Class IA injuries involve the central avascular portion of the TFC with a rim still attached to the radius (RUL respected). Class IA injuries are usually full-thickness tears, so DRUJ and radiocarpal joint communication is observed at arthrography, and the perforated area can be measured by CT and MR arthrography (►**Figs. 5**, **6**). If RULs are not affected, DRUJ instability is not present. This lesion is generally not amenable to direct repair. Because the articular disc is avascular, there is little chance for healing with repair; thus debridement of the central tears to remove any flaps that may affect joint biomechanics is the treatment of choice.[12]

Class IC (Carpal Avulsion)

Class IC tears refer to avulsion of the VUCL (ulnotriquetral or ulnolunate) from the carpal attachment. This lesion is very infrequent and usually associated with more complex wrist injuries. Sagittal MR or CT arthrography images are the best planes to assess carpal insertion of the VUCL. It is important to determine if there is an associated lunotriquetral ligament (LTL) tear. Class IC lesions could present ulnocarpal subluxation but not DRUJ instability. These injuries are variably amenable to repair.[7–12]

Traumatic Tears With DRUJ Instability

Class IB (Base of the Ulnar Styloid Detachment)

These lesions involve the ulnar insertion of TFC complex. The ulnar insertion of TFC complex, as discussed in the anatomy section, is divided into a foveal insertion (proximal lamina) and a styloid insertion (distal lamina), with the foveal insertion the main component in DRUJ stability. The variable combination of styloid fractures and ligamentous injuries of the ulnar side of the wrist has been defined as a "constellation" of ligamentous, osseous, and capsular damage.[14,25] In these tears, the rich vascularity of the periphery of the TFC complex offers a highly favorable environment for healing. Peripheral partial tears with only styloid insertion involvement (noncommunicating tear) are not associated with DRUJ instability and may be treated with arthroscopic suture of the distal lamina to the ulnar wrist capsule or ECU tendon sheath. Partial tears affecting only the foveal insertion (noncommunicating tear) are frequently misdiagnosed at radiocarpal CT or MR arthrography, due to the lack of distension of DRUJ, and because of the importance of foveal avulsion to the surgical approach (this requires reattachment of the entire TFC complex to the fovea using bone anchor or drill holes), it is recommended to start arthrography with DRUJ injection of contrast (►**Fig. 7**).[13–20] When there is detachment of both the foveal and styloid insertion of the TFC complex (complete tear), communication between DRUJ and radiocarpal joint is observed at arthrography, and it is important to determine by MR arthrography the retraction of the TFC complex from its ulnar attachment because extensive laceration requires

Figure 6 (A, B) Palmer class 1A traumatic tear of the triangular fibrocartilage (TFC) complex. Coronal and sagittal CT arthrogram images show a radial side central tear of the TFC (arrows), respecting both the distal radioulnar joint (DRUL) and volar radioulnar ligament (VRUL) (B, arrowheads). MR imaging offers an accurate evaluation of Palmer class 1A and 1D lesions (up to 95% accuracy). CT/MR arthrography does not offer significant additional information in these injuries.

reconstruction with a tendon graft. CT arthrography is recommended together with MR arthrography to increase diagnostic accuracy of foveal tears and to assess associated bone fragments, such as a small bony flake from the foveal area or ulnar styloid nonunion (pseudoarthrosis).[14,16,19]

The supposition that the DRUJ is unstable when the nonunion of fracture is located at the base (type II) of the ulnar styloid process, and the opposite when the nonunion is at the tip (type I) has not been confirmed in several arthroscopic studies. Type II nonunion without associated TFCC

Figure 7 Palmer class 1B traumatic tear of the triangular fibrocartilage (TFC) complex in a patient with moderate radioulnar joint instability at clinical examination. Coronal distal radioulnar joint (DRUJ) MR arthrogram image reveals a foveal tear (arrow) of the TFC and intact styloid insertion (arrowhead) without communication with the radiocarpal compartment. Palmer class 1B lesion is one of the main indications of MR arthrography that can precisely detect partial (noncommunicating tears) and complete tears of the ulnar attachment of the TFC.

Figure 8 Palmer class 1D traumatic tear of the triangular fibrocartilage (TFC) complex in a patient with ulnar wrist pain and without radioulnar joint instability. Coronal fat-suppressed T1-weighted MR arthrogram image shows an avulsion of the TFC radial attachment (arrow). Dorsal radioulnar ligament (DRUL) and volar radioulnar ligament (VRUL) (not shown) are respected. Note also a tear of the lunotriquetral ligament (arrowhead).

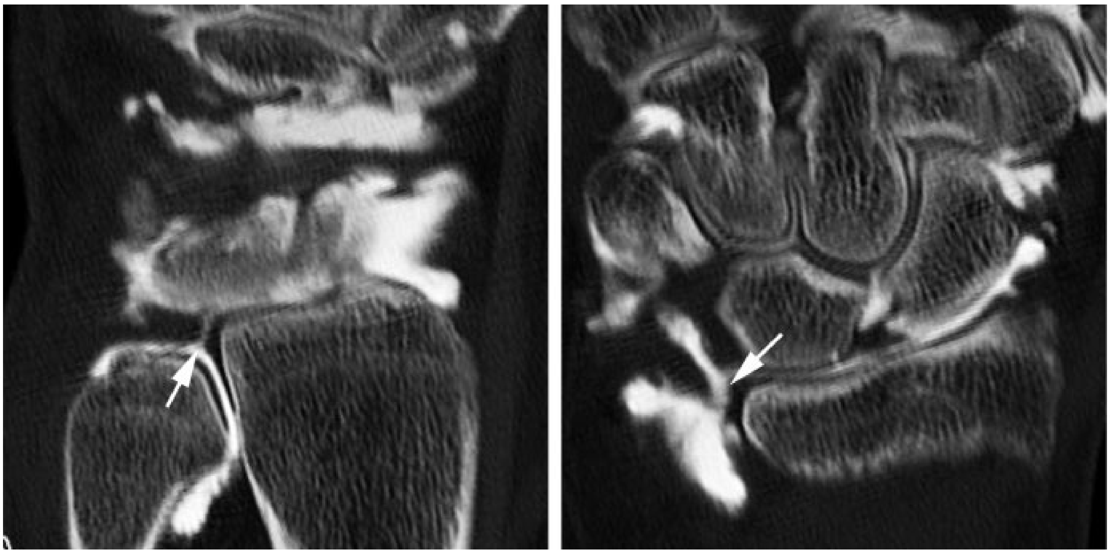

Figure 9 (A, B) Palmer class 1D traumatic tear of the triangular fibrocartilage (TFC) complex in a patient with severe radioulnar joint instability. Coronal CT arthrogram images show an avulsion of the TFC radial attachment, affecting both the dorsal radioulnar ligament and volar radioulnar ligament (arrows).

injury is seen frequently in the elderly population (osteoporotic bone) and the DRUJ is clinically stable. In nonunions of the ulnar styloid process associated with foveal detachment of the TFC complex (noncommunicating tear), DRUJ instability is expected and foveal refixation is the treatment of choice. If there is a complete tear of the ulnar insertion of TFC complex and nonunion of the ulnar styloid, the "floating styloid" is excised and foveal refixation of the TFC complex is also performed.[14–19]

Class ID (Ra"D"Ial Detachment)

As discussed in the anatomy section, the connection from the hyaline cartilage of the radius to the TFC indicates a rather weaker connection than the peripheral ligament–bone connection. The radial tears of the TFC complex include fibrocartilage central tear and dorsal or palmar rim tear (involvement of RUL); the latter two may induce DRUJ instability. DRUJ and radiocarpal joint communication is usually observed at arthrography (communicating tears). The radial slit or flap tear limited to the fibrocartilage area is the most commonly seen and just needs arthroscopic partial resection (►**Fig. 8**). Dorsal or radial rim tears must be repaired to prevent DRUJ instability (►**Fig. 9**), and refixation of RUL is indicated. CT arthrography is useful to assess associated fractures, such as dorsal sigmoid notch avulsion or distal radius fracture with intra-articular (DRUJ) extension.[21,22]

The shape of the fibrocartilaginous disk of the TFC complex has been found to change between the supinated and pronated positions of the wrist when investigated with high-resolution MR imaging performed with a specially designed surface coil. The TFC complex disk was found to thin slightly during pronation at coronal imaging.[2]

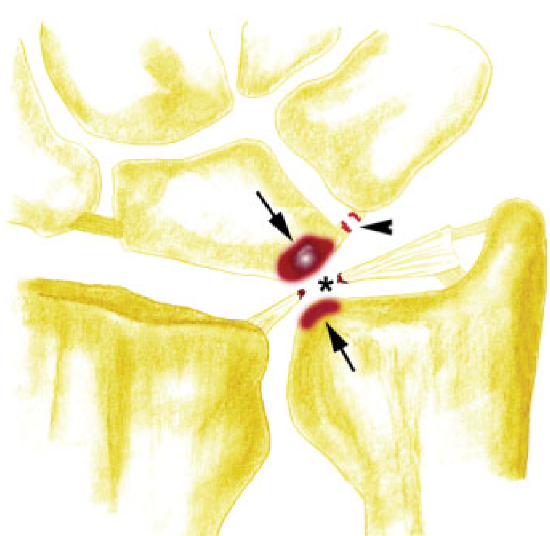

Figure 10 Diagram illustrates the full spectrum of pathological conditions in ulnar impaction syndrome, including chondromalacia of the ulnar head and the ulnar side of the lunate bone (arrows), central perforation of the triangular fibrocartilage (asterisk), and lunotriquetral ligament tear (arrowhead).

Clinical Assessment and Arthroscopic Tests

DRUJ injury must be suspected when, on examination, there is a lack of pronation or supination (with or without elbow injury). Most of the distal radioulnar dislocations are dorsal and caused by a mechanism of pronation and wrist extension that occurs in a fall with an outstretched hand. Dorsal dislocations of the ulna present with a dorsoulnar prominence with a block to supination; in volar dislocations, a volar-ulnar prominence is associated with a palpable radial sigmoid notch and a block to pronation.[14]

The most reliable clinical sign of class 1B tears is the ulnar fovea sign, whereby the patient has point tenderness over the ulnar capsule just palmar to the ECU tendon, and pain is exacerbated by passive forearm rotation. The ballottement test is a simple and reliable test to assess DRUJ laxity and consists of passive translation of the ulna on the radius in

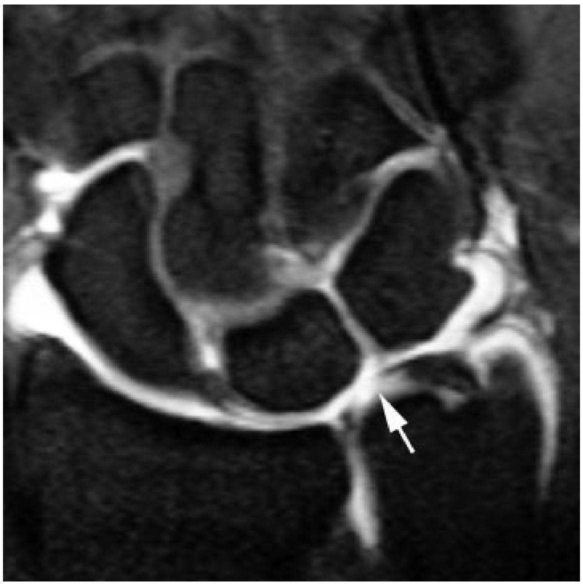

Figure 11 Palmer class IIC lesion (ulnar impaction syndrome). Coronal fat-suppressed T1-weighted MR arthrogram image demonstrates an extensive central triangular fibrocartilage perforation with contrast material communication between the radiocarpal and distal radioulnar joint compartments (arrow).

neutral rotation, full supination, and pronation. The test is repeated with the forearm in full supination and pronation. Abnormal translation relative to the contralateral side in neutral rotation suggests complete TFC complex disruption. If the translation is abnormal when the forearm is held in full supination, the DRUL is ruptured. However, when the translation is abnormal in full pronation, then the VRUL is incompetent. If a "firm" end point is shown, DRUJ is unlikely to progress toward a clinically symptomatic instability. However, the DRUJ showing an increased passive anteroposterior laxity with a "soft" end-point resistance is prone to develop clinical DRUJ instability.[11–13]

At arthroscopy, TFC complex tension is assessed by the trampoline test, which evaluates the TFC complex resilience by applying a compressive load across it with the probe. The test is positive when the TFC complex is soft and compliant, usually due to a tear at its ulnar attachment. The hook test evaluates foveal avulsion. It consists of applying traction to the ulnar-most border of the TFC complex with the probe inserted and is considered positive when the TFC complex can be lifted distally and radially toward the center of the radiocarpal joint.[14–20]

Degenerative Tears of the TFC Complex: Ulnocarpal Impaction Syndrome

Ulnocarpal impaction (UCI) is a degenerative condition characterized by chronic impaction between the ulnar head, the TFC complex, and the ulnar carpus resulting in a continuum of pathological changes (►**Fig. 10**). UCI most commonly occurs with positive ulnar variance. The most common predisposing factors include congenital positive ulnar variance and malunion of the distal radius. Palmer Classes IIA to E (degenerative) lesions demonstrate the entire spectrum of findings in UCI and are subclassified according to the degree of involvement of structures on the ulnar side of the wrist, highlighting the progressive nature of these injuries (►**Table 1**). Ulnar styloid impaction may be also associated. These impaction syndromes must be distinguished from ulnar impingement, which consists of a short ulna impinging on the distal portion of the radius.[26,27]

Ulnar variance should be measured on the posteroanterior (PA) wrist radiograph made with the forearm in neutral rotation and the shoulder and elbow in 90 degrees of flexion. If the ulna is long relative to the radius, this is considered ulna positive (or plus), and if the ulna is short relative to the radius, this is considered ulna negative (or minus). Positive ulnar variance may lead to increased ulnar carpal loading with resultant UCI. The TFC is anatomically thinner in such cases, so it is more likely to be affected. In a study of 17 patients with arthroscopic debridement of degenerative tears of TFC, patients with an ulna plus variance showed a significantly increased number of apoptotic cells in comparison with patients with an ulna neutral variance.[20] Full forearm pronation increases ulnar variance, whereas full forearm supination decreases it. Ulnar variance also becomes more positive with closed grip and returns to its original state with cessation of grip. So it is recommended to add a pronated closed grip radiograph to better assess the dynamic UCI syndrome.[26–28]

Degenerative injuries of TFC complex are extremely common and age related, present in nearly one of every two subjects $>$50 years of age, as demonstrated by Mikić[29] in an anatomical study. The changes are more frequent on the ulnar (proximal) surface of the TFC complex, and they are located in the central part but in a more ulnar-sided location than traumatic injury (class IA). Degenerative lesions are usually associated with ulnocarpal chondromalacia. The cartilage changes occur on the inferomedial aspect of the lunate and on the more radial portion of the ulnar head. The patient's age, the location of the injury, clinical history, and associated injuries are criteria that may be helpful to differentiate traumatic or degenerative etiology. Because degenerative perforations of the TFC complex may be so common in older patients, who may be asymptomatic, Gilula and Palmer have objected to the use of the term *tear* or *perforation* for these lesions and prefer the term *defect*. Palmer class IIA injury represents a (nonperforated) defect from the undersurface TFC complex, so it is important to start arthrography technique with DRUJ introduction of contrast, to better assess the defect of the ulnar surface of the TFC. In class IIB to E, lunate, triquetrum, and/or ulnar chondromalacia is visualized. Class IIC injury represents a perforated defect of the TFC complex, so communication between DRUJ and ulnocarpal joint is observed at arthrography (►**Figs. 11**, **12**). In classes IID and E, there is also communication to the midcarpal joint, due to LTL rupture (►**Fig. 12**). In class IIE, ulnocarpal osteoarthritis is also observed.[26–28]

The main problem in the diagnosis of degenerative TFC lesions is to determine if the LTL is intact (Class 2A to C) or torn (stage 2D and E). In these cases, the diagnostic reliability of conventional MRI is limited. MR and CT arthrography allow

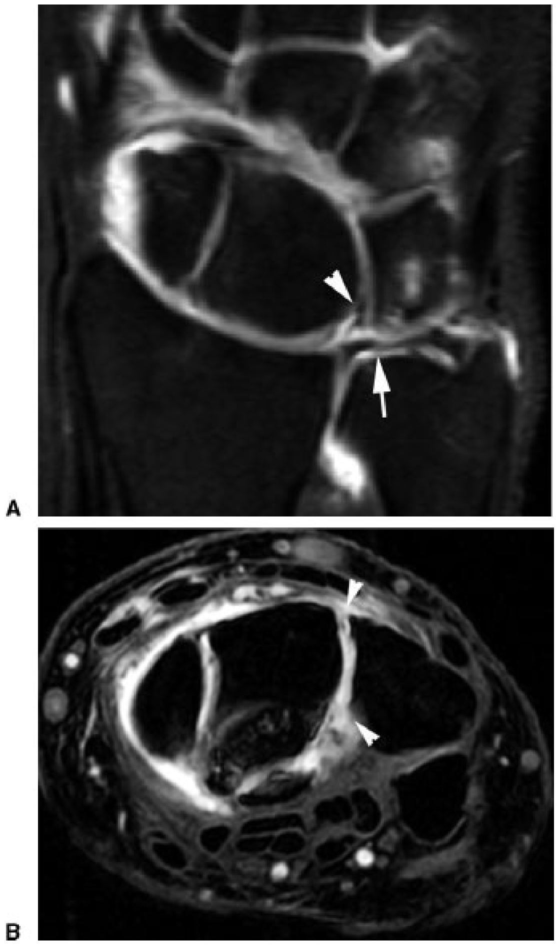

Figure 12 (A, B) Palmer class IID lesion (ulnar impaction syndrome). Coronal and axial fat-suppressed T1-weighted MR arthrogram images demonstrate a central triangular fibrocartilage perforation (A, arrow) and a chronic complete tear of the lunotriquetral ligament (arrowheads). The diagnostic reliability of conventional MR imaging is limited in the diagnosis of the lunotriquetral ligament tears (stage 2D). MR arthrography allows an accurate diagnosis of these injuries.

an accurate diagnosis of TFC complex and LTL involvement. This diagnosis is important because treatment is completely different. Stage 2A to C are treated with open (2A and B) or arthroscopic (2C, through the perforated defect) wafer procedure, in which 2 to 3 mm of the distal portion of the dome of the ulnar head are resected. Stage 2D is usually treated with ulnar shaft-shortening osteotomy to reinforce the ligaments and ulnar capsule. When there are osteoarthritic changes caused by the end stage of ulnar impaction (class 2E), these lesions will not recover completely, and treatment options usually include salvage procedures, such as resection of the ulnar head.[28]

Tolat described three types of DRUJ depending on the morphology of the articular surfaces in the coronal plane. In type 1 the inclination of the articular surfaces of the radial sigmoid notch and ulnar head is perpendicular and parallel. In type 2 and 3, the joint surfaces are joined with oblique disposition, and the proximal end is directed toward the radius (type 2) or the ulna (type 3). This is especially important when ulnar shaft shortening osteotomy is considered (class 2D). If performed, ulnar shortening in patients with type 3 Tolat morphology can result in significantly increased pressure in the proximal margin of the radial notch on the opposite margin of the head of the ulna, leading to early degenerative changes and treatment failure.[26,27]

Carpal Instability

Both intrinsic and extrinsic ligaments of the wrist contribute to wrist stability. Oftentimes, injuries to the intrinsic ligaments are associated with injuries to the extrinsic volar and dorsal ligaments, thereby resulting in chronic wrist dysfunction and pain.[30,31]

Most wrist ligamentous injuries are due to indirect trauma, usually consisting of extreme extension, combined with ulnar deviation and radiocarpal-midcarpal supination.

Carpal instability is synonymous with carpal dysfunction, thereby implying that in a normal wrist, loads are transferred without sudden changes of stress on the articular cartilage (normal kinetics) and the carpal bones move through the normal range of motion without sudden change in intercarpal alignment (normal kinematics).[30–33]

The four major patterns of carpal instability according to the Mayo classification are dissociative carpal instability (CID), nondissociative carpal instability (CIND), complex carpal instability (CIC), and adaptive carpal instability (CIA).[30–33] CID implies injury to one of the major intrinsic ligaments (e.g., scapholunate or lunotriquetral) or capitate-hamate axial disruption. CIND implies an injury to a major extrinsic ligament with intact intrinsic ligaments such as can be seen in radiocarpal instability or midcarpal instability. If CID and CIND occur concurrently, it is can result in and be classified as CIC. If carpal instability is located proximal or distal to the wrist, as opposed to being at the level of the wrist, it is classified as CIA.

Wrist instabilities may be also classified as predynamic, dynamic, or static. In predynamic instability, plain radiographs, clenched fist films, and fluoroscopy are negative, but the instability/tear is diagnosed with arthroscopy. Dynamic instability is apparent on stress views (clenched fist views) and at dynamic fluoroscopic assessment but not evident on normal radiographs. Static instability is evident on plain radiographs.[30–35]

There is no single treatment for carpal instability. The treatment is based on six basic criteria: chronicity (healing potential of the ligaments involved), constancy (dynamic or static), etiology (traumatic, congenital, or inflammatory), location (site of the major dysfunction), direction of the abnormal rotation and/or translocation of the carpal bones, and pattern of instability (CID, CIND, CIC, or CIA). Acute ligament injuries with complete intrinsic ligament rupture and overt dissociation should be treated as soon as possible because the ability to heal decreases rapidly. Acute injuries respond to simple immobilization for 4 to 6 weeks, if minor, but require percutaneous Kirschner wiring if the injury is moderate to severe. Ligament reinsertion and repair are performed with transosseous stitching or mini bone anchors. Repairs may become impossible after 6 weeks. Chronic

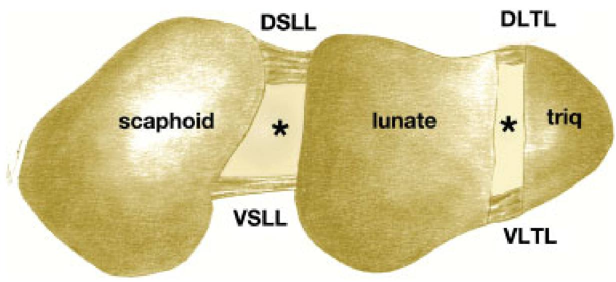

Figure 13 Diagram illustrates the scapholunate and lunotriquetral ligament anatomy. Dorsal scapholunate ligament and volar lunotriquetral ligament are the strongest ligaments and play an important role in wrist stability. DLTL, dorsal lunotriquetral ligament; DSLL, dorsal scapholunate ligament; VLTL, volar lunotriquetral ligament; VSLL, volar scapholunate ligament; asterisk indicates fibrocartilaginous central portion of the scapholunate and lunotriquetral ligaments.

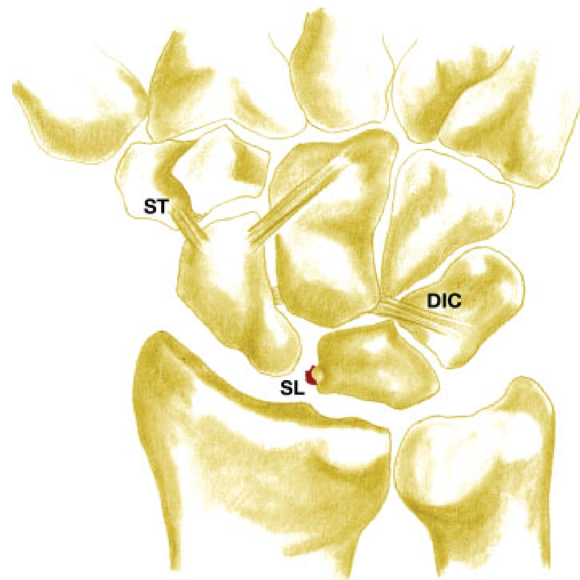

Figure 15 Diagram illustrates the dynamic form of scapholunate dissociation. Scapholunate ligament disruption at scaphoid insertion (most common location of scapholunate ligament tear) with intact secondary ligaments stabilizers. Isolated scapholunate ligament disruption does not cause diastasis or permanent carpal malalignment unless there is a concomitant failure of the secondary scaphoid stabilizers. DIC, dorsal intercarpal ligament; SL, scapholunate ligament; ST, scaphotrapezoid ligament.

injuries are best currently managed through a tendon graft reconstruction of the ligament instead of arthrodesis, for which prognosis is poorer and the nonunion rate is higher.[30,35–38]

Anatomy of Carpal Ligaments

The proximal row of carpal bones (scaphoid, lunate, and triquetrum) are linked via their intrinsic ligaments and form the “intercalated segment,” which is interposed between the distal carpal row distally (“the fixed unit”), and the radius and TFC complex proximally.[30,31,33,34]

Both intrinsic ligaments of the proximal carpal row, the SL and LT ligaments, are C-shaped structures with three components: dorsal, proximal, and volar (►**Fig. 13**). Dorsal and volar portions are true ligaments, whereas proximal portions are thin fibrocartilaginous membranes with no stabilizing role. The dorsal component of SL and the volar component of LT are the strongest ligaments and the main stabilizers of the intercalated segment.[1,2,5] The scaphoid attachment of the dorsal component of SL ligament and the triquetral

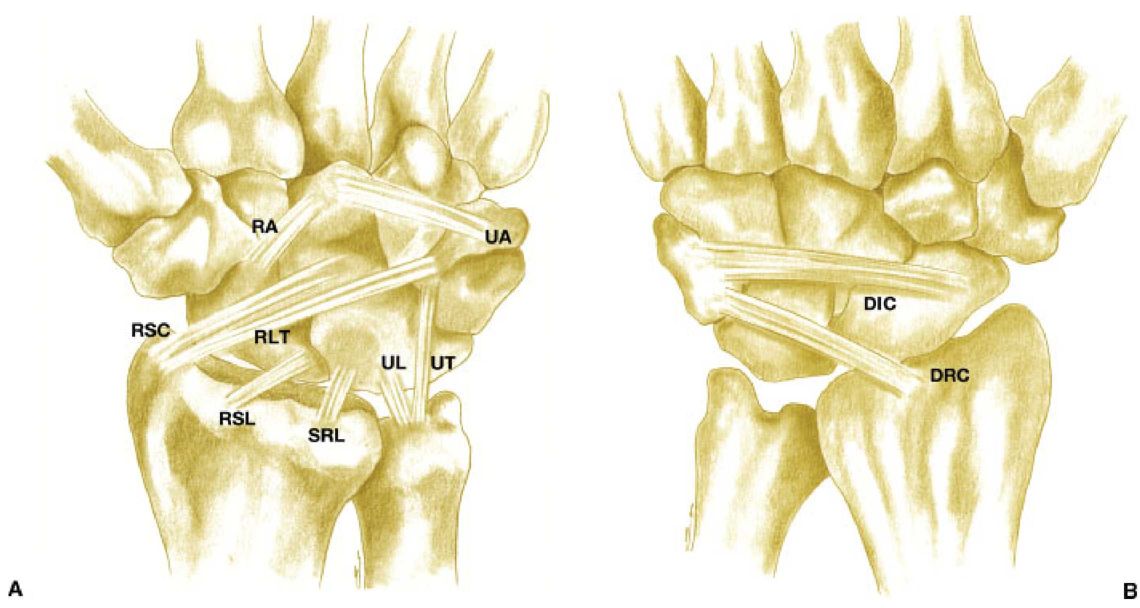

Figure 14 (A) Anatomy of the volar extrinsic ligaments. Diagram illustrating the extrinsic radiocarpal and ulnocarpal ligaments. RA, radial arm of the deltoid ligament; RLT, radiolunotriquetral; RSL, radioscapholunate ligament; RSC, radioscaphocapitate; SRL, short radiolunate ligament; UA, ulnar arm of the deltoid ligament; UL, ulnolunate ligament; UT, ulnotriquetral ligament. (B) Anatomy of the dorsal extrinsic ligaments. Diagram illustrating the dorsal extrinsic radiocarpal ligaments. DIC, dorsal intercarpal ligament; DRC, dorsal radiocarpal ligament.

Figure 16 Diagram illustrates the static form of scapholunate dissociation. Scapholunate ligament and secondary scaphoid stabilizers disruption results in a proximal dissociative carpal instability-volar intercalated segment instability pattern of carpal collapse. The scaphoid, devoid of proximal constraints, adopts a flexed posture (right curved arrow). The lunate, by contrast, follows its natural tendency toward extension with the triquetrum (left curved arrow).

attachment of the volar component of LT ligament are more likely to avulse than the stronger lunate attachment.[1,2]

From a biomechanical point of view, in the intercalated segment, the lunate is kept in balance due to the opposing two forces transmitted through the intrinsic ligaments: the volar scaphoid (flexion) and dorsal triquetrum (extension) inclination tendency. On a wrist lateral plain film, the angle formed between the longitudinal axis of the scaphoid and lunate normally range from 30 to 60 degrees, and the lunate-capitate angle from 0 to 30 degrees. In SL static dissociation, the lunate follows dorsal inclination with the triquetrum while the scaphoid is volarly flexed, so the SL angle is >60 degrees and the capitate-lunate angle is >30 degrees; this is termed *dorsal intercalated segment instability* (DISI). In LT static dissociation the lunate follows volar flexion with the scaphoid while the triquetrum is extended, so the SL angle is <30 degrees and the capitate-lunate angle (as DISI) is >30 degrees; this is termed *volar intercalated segment instability* (VISI).[1,2,7,31,33]

Volar extrinsic radiocarpal ligaments include volar radioscaphocapitate (VRSC), volar radiolunotriquetral (VRLT, or long radiolunate), radioscapholunate, and (short) radiolunate ligaments (►**Fig. 14A**). Volar extrinsic ulnocarpal ligaments are composed of the ulnolunate and ulnotriquetral ligaments, which were described in the TFC anatomy. The arcuate ligament is an inverted V-shaped volar extrinsic ligament with a triquetrohamocapitate (ulnar) and a capitoscaphoid (radial) arm. The dorsal extrinsic radiocarpal ligaments include the dorsal radiocarpal (DRC) and dorsal intercarpal (DIC) (►**Fig. 14B**). The VRSC and VRLT ligaments on the volar aspect and the DRC and DIC ligaments on the dorsal aspect are the main extrinsic stabilizer ligaments of the wrist.[1,30,31,33]

Dissociative Instability

Scapholunate Dissociation

The most commonly injured wrist ligament is the SL ligament.[1,30,36] Symptomatic dysfunction that results from the loss of the mechanical linkage between the scaphoid and the lunate (with or without carpal malalignment) has been termed *SL dissociation*.[1,30,36]

Three distinct structures comprise the SL linkage: the volar and dorsal components of the SL ligament and the proximal fibrocartilaginous membrane. The dorsal SL ligament, which plays the key role in SL instability, is located along the deep surface of the dorsal wrist capsule and connects the dorsal aspects of the scaphoid and lunate.[1,2,5,30]

Although isolated SL ligament disruption may not result in immediate and complete diastasis or radiographic malalignment, such disruption is a prerequisite for the development of SL dissociation. With a disrupted SL ligament, there is increased motion between the two bones that generates shear stress, thereby resulting in synovitis and pain (predynamic and dynamic clinical forms of SL dissociation).[30]

Permanent carpal malalignment is not seen unless there is concomitant disruption of the secondary stabilizers of the scaphoid such as the volar distal scaphotrapezial dorsal intercarpal and SL ligaments (►**Fig. 15**).[30,36] This can be seen primarily or acutely in the setting of hyperextension stress or secondarily due to progressive stretching of these structures. Complete disruption of the ligaments between the scaphoid and lunate results in proximal CID and DISI. With loss of its proximal restraints, the scaphoid rotates around the radiocapitate ligament with subsequent dorsal subluxation of its proximal pole. The lunate follows its natural tendency toward extension, a tendency accentuated by the extension movement of the triquetrum (►**Fig. 16**).[30,36] Over time, there is subsequent development of degenerative arthritis.[30]

Patients with SL ligament injuries have pain with direct palpation over the SL interval. Wrist motion may only be appreciably impaired once degenerative arthritis has developed.[30,36]

Initially, suspected SL injuries are evaluated with radiographs. In static SL instability, there will be an increased SL interval on neutral PA radiographs. This interval can be accentuated with a clenched fist view. If the SL interval is >3 mm or the interval on the symptomatic side is greater than the asymptomatic contralateral interval, the SL ligament may be disrupted. Such disruptions may also result in a DISI pattern of malalignment with dorsal angulation of the lunate (in the sagittal plane), dorsal displacement of the capitate in relation to the radiometacarpal axis, and a radiolunate angle >10 degrees. In addition, the angle formed by the longitudinal axis of the scaphoid and the lunate measures >70 degrees (normal: 30 to 60 degrees).[30,36]

Coronal and axial MR images are best for direct evaluation of the SL ligament.[1,34] Partial tears and elongated but otherwise intact ligaments may be visualized. With a partial tear,

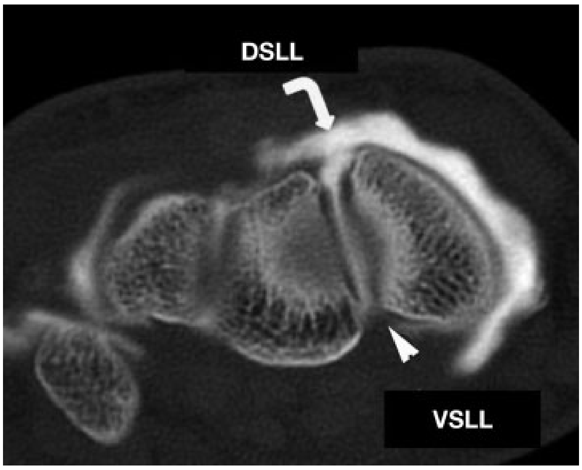

Figure 17 Partial tear of the scapholunate ligament (predynamic form of scapholunate dissociation). Axial CT arthrogram image reveals partial tear of the scapholunate ligament affecting the dorsal component (arrow). The volar component of the scapholunate ligament is intact (arrowhead). DSLL, dorsal scapholunate ligament; VSLL, volar scapholunate ligament.

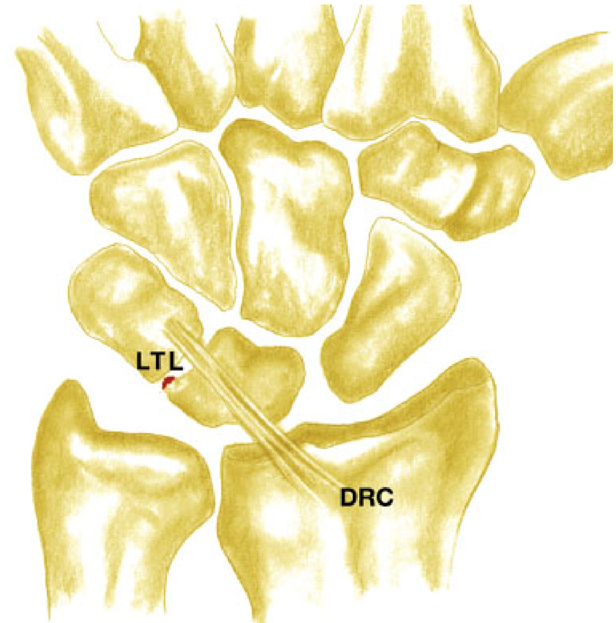

Figure 19 Diagram illustrates the dynamic form of lunotriquetral dissociation. Lunotriquetral ligament disruption with intact dorsal radiocarpal ligament (secondary stabilizer). Isolated lunotriquetral ligament disruption does not cause permanent carpal malalignment unless there is a concomitant failure of the dorsal radiocarpal ligament. DRC, dorsal radiocarpal ligament; LTL, lunotriquetral ligament.

there is focal thinning or irregularity or high signal intensity in a portion of the ligament. This is most often seen in the central and volar portions of the ligament that are also the weakest portions of the ligament.[1,34] A discrete discontinuity of the SL ligament or nonvisualization of the ligament are indicative of a complete tear. Although nonspecific, fluid in the midcarpal joint may be a sensitive sign for SL ligament tears.[1] With more advanced cases, if there is involvement of the volar scaphotrapezial, dorsal intercarpal, and scaphocapitate ligaments, there can be widening of the SL interval.

CT arthrography and MR arthrography are more sensitive than standard MRI in the detection of SL tears, particularly for more subtle injuries.[1,34] With CT/MR arthrography, the exact location and extent of a tear are better seen, thereby helping to differentiate degenerative-type lesions that may only involve the membranous portion of the ligament from acute tears that involve the dorsal or palmar components (►**Figs. 17**, **18**). Although membranous tears can be painful, they do not imply instability of the type that can be seen with tears of the dorsal component.[1] At CT/MR arthrography, a tear of the SL ligament will result in contrast extending from the radiocarpal to the midcarpal joint, or vice versa, depending on the joint that was injected. With partial tears, the contrast

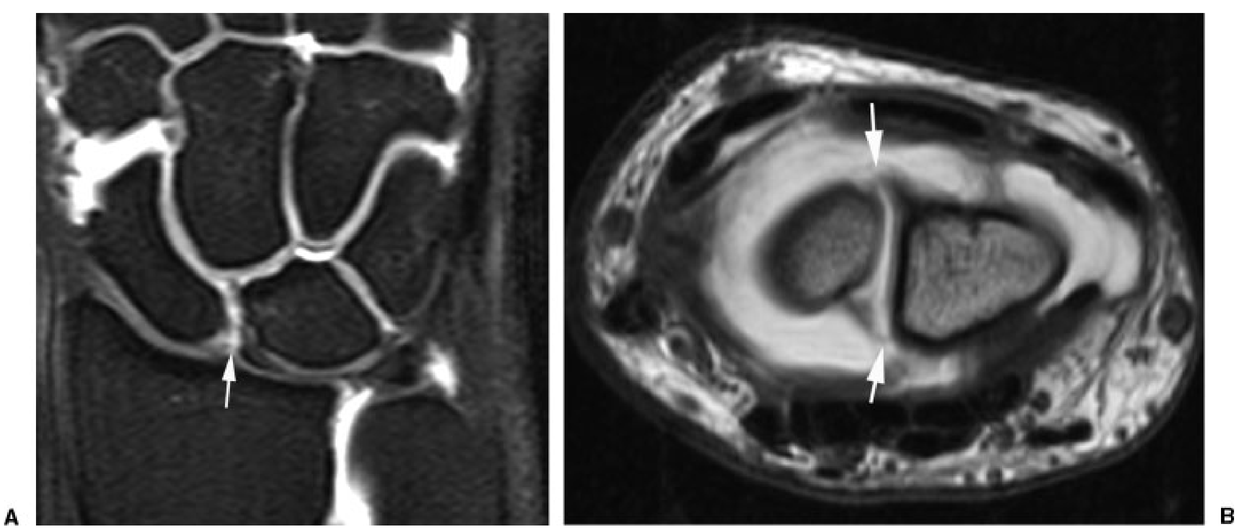

Figure 18 (A) Chronic scapholunate ligament tear (dynamic form of scapholunate dissociation). Coronal fat-suppressed T1-weighted MR arthrogram image reveals a complete scapholunate ligament tear with widening of the scapholunate interval (arrow). (B) Axial T1-weighted MR arthrogram image shows a complete rupture of both the dorsal and volar components of the scapholunate ligament (arrows).

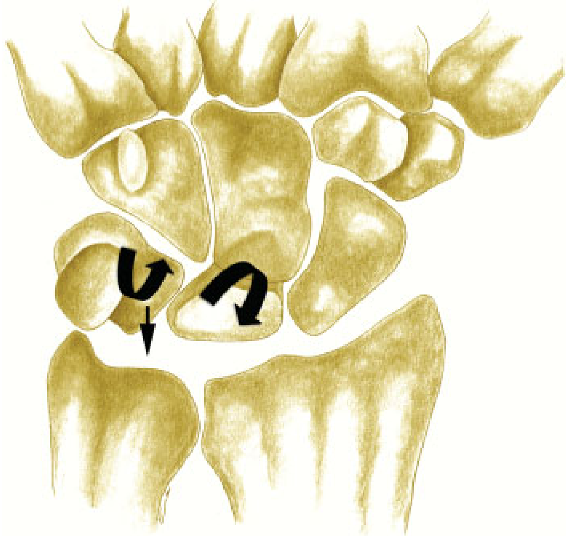

Figure 20 Diagram illustrates the static form of lunotriquetral dissociation. Lunotriquetral ligament and dorsal radiocarpal ligament disruption results in a proximal dissociative carpal instability-volar intercalated segment instability pattern of carpal collapse. The triquetrum is translated proximally (arrow) and adopts an extended posture (left curved arrow). The lunate, by contrast, follows the scaphoid in flexion (right curved arrow).

will outline the abnormal morphology of the ligament and may imbibe into the damaged fibers. Also, if the ligament has been previously torn, then scarred down, CT/MR arthrography will demonstrate the abnormal morphology of the scarred remnant. Finally, CT/MR arthrography can also demonstrate peripheral avulsions of the SL ligament with a detached but otherwise morphologically normal ligament.[1]

Advances in multislice equipment allow one to combine in the same study the anatomical information provided by the CT arthrography (assessment of ligaments, associated cartilage, and bone lesions) with dynamic information, making this technique the method of choice in the evaluation of carpal instability.

Acute injuries with a complete SL ligament tear and dissociation should be treated early because delayed treatment is associated with decreased healing capacity.[30,36] The typical treatment involves detaching the ligament from the scaphoid and then reattaching it either with a transosseous suture or mini bone anchors. Mild stable or nondissociated injuries can be treated with 4 to 6 weeks of immobilization, whereas moderate to severe stable injuries may require short-term percutaneous fixation with Kirschner wires. Isolated injuries to the most proximal membranous portion (which does not play a significant role in mechanical stability) of the SL ligament can be treated with arthroscopic debridement, thereby allowing immediate mobilization of the joint and rapid recovery.[30,36] Chronic complete SL dissociations can be treated in a variety of ways depending on the clinical scenario. Options include complete ligament reconstructions to SL arthrodesis.[30,36–38]

Lunotriquetral Instability

As with the SL joint, two interosseous ligaments stabilize the LT joint. These consist of the volar and dorsal LT ligaments with an intervening fibrocartilaginous membrane. However, in contrast to the SL joint, the volar LT ligament is stronger than the dorsal LT ligament.[1,30,38]

Compared with SL injuries, LT injuries are quite uncommon. Frequently, either the injury is missed or is misdiagnosed as another ulnar-sided wrist lesion such as midcarpal instability or a TFC complex injury.[30,38]

Complete disruption of the LT ligament in combination with insufficiency of the secondary stabilizer, the radiolunotriquetral ligament (►**Fig. 19**), will result in a pattern of VISI (►**Fig. 20**). In this setting, the scaphoid forces the lunate into palmar flexion with concomitant proximal translocation of the triquetrum.[30,36] These patients will present with ulnar-sided wrist pain and demonstrate point tenderness over the LT interval.[30,38]

Isolated LT tears usually show no radiographic abnormality. However, in more severe cases where there is an injury to the secondary restrains, the wrist will assume a VISI configuration with palmar angulation of the lunate (radiolunate angle 10 degrees volar) with palmar displacement of the capitate in relation to the metacarpal axis. The longitudinal SL axis will decrease and be $<$30 degrees.[30]

On conventional MRI, ligament disruption is typically best seen on the T2*-weighted or fat-suppressed T2-weighted images obtained in the coronal plane and is manifested either as complete disruption of the ligament or a focal linear T2 bright partial- or full-thickness defect in the ligament. Nonvisualization of the ligament is not a very reliable sign of ligament injury because the LT ligament is not as well seen on routine MR as, for instance, the SL ligament.[1,36]

The imaging modality of choice for visualizing the LT ligament is CT/MR arthrography because it allows accurate

Figure 21 Traumatic ulnar translocation of the carpus (complex carpal instability). Coronal T1-weighted MR arthrogram image shows a rupture of the scapholunate ligament (arrow), complete rupture of the radiolunotriquetral and the radioscapholunate ligaments (arrowhead), and tear of the central portion of the triangular fibrocartilage (asterisk).

visualization of the size, location, and morphology of LT tears (►Figs. 8, 12).[1] This type of detailed information is necessary because communication across a small membranous perforation or deficiency of the membranous portion of the ligament may not be clinically significant if the volar and dorsal components of the ligament are intact. In complete tears of the ligament, the intra-articular contrast will demonstrate communication between the radiocarpal and midcarpal joints.[1]

Management strategies of LT injuries are somewhat similar to those of SL injuries in that early primary repair via transosseous reinsertion can be undertaken if there is no delay in diagnosis of the injury.[30,38] Chronic injuries are best treated with reconstruction as opposed to arthrodesis because the latter carries a poorer prognosis and has a relatively high nonunion rate. One reconstruction method involves splitting the extensor carpi ulnaris tendon, which is then sectioned proximally (and left attached distally), passing the tendon through drill holes in the triquetrum, then suturing it back to itself proximally.[30,38]

Nondissociative Instability and Complex Carpal Instability

CINDs are characterized by joint dysfunction either between the forearm and the proximal carpal row (radiocarpal CIND) or between the proximal and distal rows (midcarpal CIND) while the articular function is preserved within each row. Unfortunately, exactly which ligaments are involved with these instabilities, and the precise nature and degree of injury to the ligaments, remain controversial. Among the extrinsic ligaments, the VRLT and VRSC ligaments are the most important for radiocarpal stability. Any failure of these controlling forces is likely to result in an ulnar and volar translocation shift of the carpus leading to deformity and dysfunction of the wrist.[34,39]

Midcarpal instability (MCI) is a dynamic disorder associated with injury of the (volar) arcuate ligament. Palmar MCI is the most common type. The arcuate ligament has a broader and thicker ulnar arm (triquetrohamocapitate ligament), and its injury along with DRC involvement is associated with palmar MCI. Normally, the proximal carpal row smoothly transitions between a flexed and an extended position as the wrist moves from radial to ulnar deviation. During this motion, the arcuate ligament becomes taut and assists in pulling the proximal carpal row into extension. In dynamic palmar MCI, there is often tenderness over the triquetrohamate joint and a symptomatic "clunk" is observed when moving the wrist into ulnar deviation and pronation because when the ulnar arm of arcuate ligament becomes deficient, the proximal carpal row remains in a flexed position until the triquetrum engages the hamate and the proximal row alignment abruptly changes from flexion to extension, resulting in a painful "clunk." These sudden changes in alignment serve as helpful diagnostic sign during videofluoroscopy. In static palmar MCI, the entire proximal carpal row appears abnormally flexed in the PA radiograph (the flexed scaphoid produces a ring sign). This nondissociative VISI pattern results in an increased capitate-lunate angle (>30 degrees) on the lateral view; however, the SL angle is within normal ranges (30 to 60 degrees).[40]

CIC patterns are not that uncommon. For example, perilunate dislocations are associated with complex ligament injuries at both the radiocarpal (radiolunate and radiocapitate ligaments) and intercarpal (SL and LT ligaments) articulations. If these injuries do not heal properly, there may be resultant chronic SL and LT dissociation (CID pattern) as well as ulnar translation of the lunate (CIND pattern).[30]

Extrinsic carpal ligament injuries (volar and dorsal) are less commonly identified at MR imaging.[28] As with other ligament tears, MR findings of an injured ligament include hyperintensity, irregularity, and fraying of the ligament. Again, CT/MR arthrography is the preferred method of evaluating these ligaments because it offers excellent contrast resolution and spatial resolution of the ligaments and the surrounding structures (►Fig. 21).[1,39,40]

Conclusion

CT arthrography and MR arthrography allow a better assessment of intra-articular pathology of the wrist, especially because these techniques allow an accurate evaluation of very common injuries such as traumatic Palmer class 1B injuries that are not adequately assessed on MRI. CT/MR arthrography also characterizes the different subtypes of class 1D injuries, which is important in deciding therapeutic approach. CT/MR arthrography allows the diagnosis of traumatic injuries not included in the Palmer classification, such as capsular injuries and ulnar detachment or the Nishikawa lesion.

In TFC complex degenerative injuries, the main indication of arthrographic techniques is to determine the status of the LT ligament, to differentiate between Palmer class 2C versus 2D injuries because these have a different treatment and prognosis.

Arthrographic techniques allow a precise evaluation of intrinsic and extrinsic ligaments allowing a proper diagnosis of the early stage of carpal instability (predynamic form) with a better therapeutic outcome. The combination of CT arthrography with dynamic study on multidetector CT makes CT arthrography the technique of choice in the assessment of wrist instability.

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