MRI of the Wrist Update

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In the past, significant anatomic information concerning the painful wrist was obtained from conventional radiographs followed by arthrography, tomography, bone scintigraphy, or CT. At this time, high resolution MR imaging can be utilized to enhance detection and evaluation of several wrist disorders, allowing for discrimination of soft-tissue structures, including marrow, ligaments, tendons, cartilage, muscles, nerves, and blood vessels. MR imaging can be of aid in evaluation of carpal instability, disorders of the triangular fibrocartilage, ulnar impaction syndrome, distal radioulnar joint instability, fracture, avascular necrosis, tendinopathy, nerve entrapment syndromes, synovial abnormalities, and soft tissue masses.

IMAGING PROTOCOLS

Most patients are able to place the arm at their side with the wrist surrounded by a coil. Larger patients may need to have their arm placed above the head, which is less comfortable and tends to be associated with increased motion artifact because of this.

A variety of coils can be used for wrist imaging. We have used the following coils for wrist imaging: 1) paired circular 3" coils, 2) a shoulder coil, or 3) a small parts transmit-receive volume coil (Medical Advances, Inc., Milwaukee, Wisconsin). It is ideal to have the wrist in neutral alignment, however we have found it difficult for the patient to maintain the wrist in this position during scanning without the aid of a dorsal splint. Instead, we image the wrist prone, parallel to the table top. The fingers are extended only when we evaluate for carpal tunnel syndrome.

When imaging the wrist we use axial images as a guide with cursors aligned parallel and then perpendicular to the proximal carpal row, providing coronal and sagittal images, respectively. An axial scout sequence is followed by coronal T1-weighted and gradient echo 3DFT sequences, an axial T2-weighted fast spin-echo sequence, and a sagittal T1-weighted sequence. In some cases, we will also obtain coronal fast spin echo images to further evaluate the triangular fibrocartilage and ligaments. The field of view should be as small as possible, ranging between 8 and 10 cm. Although not routinely obtained at our institution, cine motion studies can be performed with fast imaging techniques such as gradient-echo sequences for evaluation of ligamentous abnormality and carpal instability.

LIGAMENTOUS DISRUPTION AND CARPAL INSTABILITY

There are two types of ligaments in the wrist- intrinsic and extrinsic. Both serve to maintain proper carpal alignment and when torn can result in carpal instability. With normal carpal alignment, the volar tubercle of the scaphoid lies approximately 47 degrees volar to the longitudinal axis of the wrist. This is best assessed on sagittal MR images. On sagittal images, the radius, lunate, capitate, and third metacarpal are colinear with the wrist in neutral position. When there is stretching or disruption of a ligament on the radial aspect of the wrist, the lunate may tilt dorsally, producing a dorsiflexed intercalated segmental instability (DISI) deformity. Presumably, abnormalities of ligaments on the ulnar side of the wrist, including the luno-triquetral and ulnocarpal ligaments produce a volar intercalated segment instability (VISI) pattern where the lunate is volarly flexed. DISI and VISI are well seen on sagittal MR images with the wrist in neutral position. One evaluates the angle formed between the long axis of the capitate and a perpendicular from a line drawn between the distal dorsal and volar aspect of the lunate. This angle should not measure more than 30 degrees in either direction. One must be sure that the wrist is not in ulnar deviation when evaluating for DISI as this position itself can produce some dorsal tilt of the lunate. With ulnar deviation, however, the lunate also shifts volarly with relation to the radius, which does not occur with a true DISI. Sequelae of malalignment from ligamentous tears include wrist shortening, which produces crowding in the carpal tunnel, and degenerative arthritis.

Intrinsic wrist ligaments (intercarpal ligaments)

The radiocarpal joint is separated from the midcarpal joint by interosseous ligaments that extend proximally between the scaphoid, lunate, and triquetrium and are best seen on coronal MR images. In earlier studies, Zlatkin reported an accuracy of 90% and 80%, respectively for MR evaluation of scapholunate and lunotriquetral ligament tears [1]. MR imaging demonstrated a sensitivity of 50%, specificity of 86%, and accuracy of 76% for detection of scapholunate ligament tears and sensitivity of 50%, specificity of 46%, and accuracy of 49% for detection of lunotriquetral tears in a study of 15 patients using arthrography as a gold standard [2]. In more recent studies,Totterman demonstrated improved visualization of the intrinsic wrist ligaments using three-dimensional Fourier transform MR imaging with a custom-designed wrist coil, and Smith showed that these ligaments could be well seen in asymptomatic individuals using dual echo gradient echo sequences with a dedicated linear, transmit-receive wrist coil [1,3-5].

It is important to obtain T2- or T2*-weighting to fully evaluate these ligaments. Three dimensional volume 3DFT gradient-echo techniques or dual-echo gradient-echo sequences may be used to study the intrinsic proximal row wrist ligaments [3-5]. The wrist can also be studied in various positions with MR imaging (ulnar and radial deviation, flexion and extension) when there is suspected ligamentous disruption or carpal instability [6].

The scapholunate and lunotriquetral ligaments are complex structures with at least three separate zones [7,8]. In the scapholunate ligament, the stronger dorsal and palmar thirds are intracapsular and interosseous. They provide biomechanical strength. The middle third of the scapholunate ligament is a fibrocartilaginous membrane with little contribution to ligament strength. The middle third inserts directly on hyaline cartilage of the scaphoid and lunate, while volar and dorsal components often insert directly on the carpal bones. In Smith´s series of asymptomatic wrists, the scapholunate ligament was delta-shaped on MRI in 90% and linear in the rest. The lunotriquetral ligament was delta-shaped in 63% and linear in 37% of asymptomatic wrists.

The ligaments are usually low to intermediate signal intensity on MR imaging. In all but one of the 80 asymptomatic patients in Smith´s studies of both ligaments, the signal intensity did not increase to that of fluid on T2-weighting [4,5]. Therefore, fluid signal intensity traversing these ligaments on T2-weighted images should be considered suspicious for a perforation or tear. The ligaments can be affected by age-related degeneration, similar to that seen in the triangular fibrocartilage. With degeneration, the signal intensity is increased on T1-weighted images, but decreases on T2-weighted images [9].

Tears are common in both the scapholunate and lunotriquetral ligaments and can present on high-resolution MRI as nonvisualization of the ligament, focal areas of high signal intensity within the ligament on T2-weighting, or abnormal morphology including irregular margins. Fluid may be seen in the midcarpal joint in patients with either scapholunate or lunotriquetral ligament tears [2].

Extrinsic wrist ligaments

The articular capsule is strengthened by dorsal and volar ligaments which provide wrist stability. Alignment of the carpal bones is principally maintained by the extrinsic ligaments, which may be difficult to identify and follow in their entirety on MR imaging. There is much controversy regarding the labelling of various ligaments. For purposes of this chapter, the ligaments will be referred to according to Smith´s MR classification [10,11]. The strong volar ligaments include the radioscaphocapitate, radiolunotriquetral, radiolunate, radioscapholunate (also termed the ligament of Kuenz and Testut), radioscaphoid, ulnolunate, ulnotriquetral, and triquetroscaphoid ligaments. The less clinically important dorsal radiocarpal ligaments include the radiotriquetral ligament (which arises from the dorsal rim of the radius along the ulnar margin of Lister´s tubercle and attaches to the dorsal tubercle of the triquetrium) and dorsal intercarpal ligament (which arises from the dorsal tubercle of the triquetrium and attaches to the dorsal scaphoid, radial collateral ligament, and scaphotrapeziotrapezoid complex).

Before MR imaging, little information could be obtained about these ligaments without surgical exploration. On MRI, they are best seen with three-dimensional Fourier transform MR imaging with multiplanar oblique reconstructions which allow for images in the planes of the different ligaments [3,10, 11]. Signs of an abnormal ligament on MRI include increased signal intensity on T2-weighting, a segmental defect, increased length, thickening, thinning, and nonvisualization [4]. Both volar and dorsal extrinsic ligaments are usually symmetric between the right and left sides, and therefore, images of the contralateral wrist can be used for comparison purposes in equivocal cases [10,11]. The ligaments are visualized in multiple planes. A wavy contour of the unstressed ligament may be seen in normal individuals. Current experience with MR imaging for evaluation of disruption of the extrinsic carpal ligaments is limited. Further study will be necessary to determine if ligamentous injuries can be diagnosed with MRI.

DISORDERS OF THE TRIANGULAR FIBROCARTILAGE

The triangular fibrocartilage is an important structure that cushions the ulnocarpal and stabilizes the distal radioulnar joint. Tears of the triangular fibrocartilage result in nonspecific pain, crepitus, and weakness that can be difficult to distinguish from injuries to the lunotriquetral ligament, extensor carpi ulnaris tendon, pisotriquetral, or distal radioulnar joints [12,13]. Diagnostic imaging is usually performed in these patients since clinical examination may not give a precise diagnosis for ulnar wrist pain.

Palmer and Werner have defined the triangular fibrocartilage complex (TFCC) as a composite of five structures: 1) the triangular fibrocartilage (also referred to as the "articular disc") and its two dorsal and volar capsular reinforcements (the volar and dorsal distal radioulnar ligaments); 2) the ulno-carpal meniscus, not always identified in the human wrist; 3) the ulnocarpal ligaments which add stability to the ulnar aspect of the midcarpal joint; 4) the ulnar collateral ligament, which extends from the base of the ulnar styloid to the carpus; and 5) the sheath of the extensor carpi ulnaris tendon, which inserts along the dorsal margin of the base of the fifth metacarpal [14].

The triangular fibrocartilage frequently undergoes degeneration which is often asymptomatic. Degeneration has been demonstrated on histologic studies with increasing prevalence in older individuals. In the first two decades of life, no degenerative changes were detected in Mikic´s anatomic study of 180 wrist joints from 100 cadavers. Such changes were seen in 38% and 55% of individuals in the 3rd and 4th decades of life respectively, and in up to 100% of individuals during the 6th decade [15]. More than 40% of those wrists had perforations of the triangular fibrocartilage.

Degeneration tends to be more severe on the proximal surface due to more intensive biomechanical forces on this surface [14, 15]. Progressive degeneration of the proximal surface leads to erosion, thinning, and perforation of the triangular fibrocartilage. Degenerative perforations are more common in the thinner central portion of the triangular fibrocartilage, whereas traumatic tears tend to occur in the radial portion [16].

Arthrography has been useful for excluding complete tears of the triangular fibrocartilage. Tears are indicated by leakage of contrast between the two compartments which are normally anatomically separated from each other by the triangular fibrocartilage- the radiocarpal joint and the distal radioulnar joint. The normal arthrogram demonstrates a lack of communication between the radiocarpal joint and distal radioulnar joint. Communication may occur however between these wrist compartments in 7-35% of asymptomatic individuals, presumably

Normal TFCC

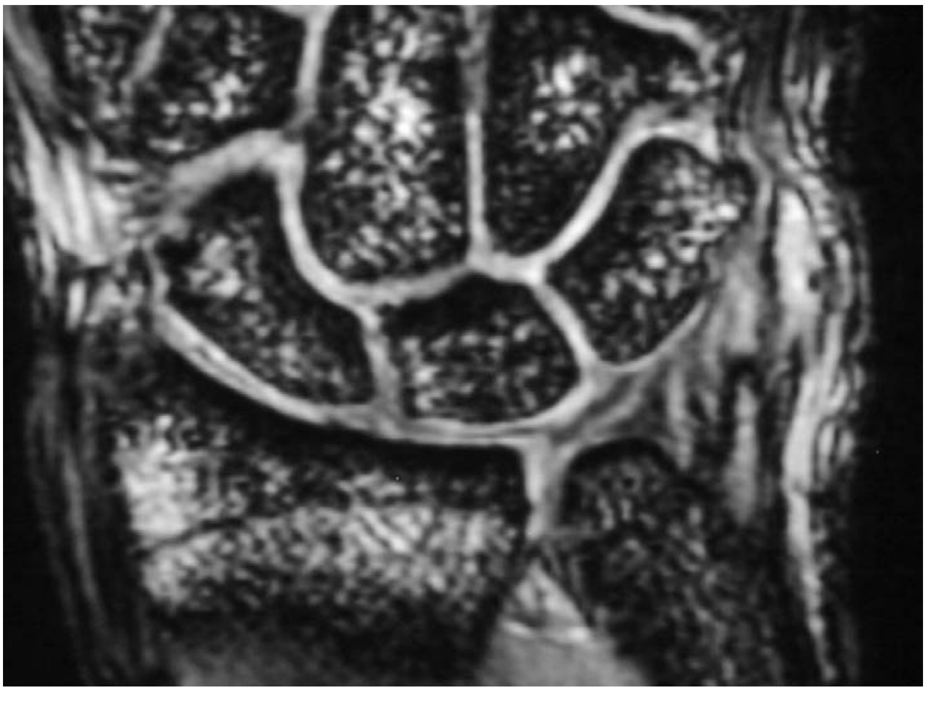
due to degenerative perforation, producing false positive arthrograms [17,18]. The prevalence of this finding increases in older individuals. Therefore a test is needed that can eliminate these false positives. MR imaging can aid in this distinction, with the potential to separate some of the degenerative from traumatic abnormalities of the triangular fibrocartilage.

MR imaging has been established as a noninvasive technique which directly evaluates the entire triangular fibrocartilage [1,19-24]. The triangular fibrocartilage is best seen on coronal images obtained with a field of view between 8 and 12 cm. It is a low signal bow tie-like structure that extends radially from the dorsal ulnar aspect of the lunate fossa where it attaches to the intermediate to high signal intensity hyaline articular cartilage of the radius. It´s ulnar attachments are to the fovea at the base of the radial aspect of the ulnar styloid and to the ulnar styloid process. The ulnar attachment is often obscured by surrounding loose vascular connective tissue which is of intermediate signal intensity. The prestyloid recess is an extension of the radiocarpal joint that also lies near the ulnar attachment of the triangular fibrocartilage. Fluid in this recess produces increased signal intensity. The low signal intensity dorsal and volar distal radioulnar ligaments are most easily seen on axial images where they extend from the radius to the ulna.

When there is degeneration of the triangular fibrocartilage, MR imaging demonstrates intermediate signal intensity on short TE images that does not increase on T2- or T2*-weighted images [9]. This is believed to be caused by synovial fluid, which diffuses into areas of degeneration and/ or an alteration of chemical binding components for "free water" [9,25,26]. Sugimoto recently reported that high signal intensity was seen in half of the 70 asymptomatic triangular fibrocartilages imaged with spoiled gradient-recalled echo images obtained with the following parameters:TR=55; TE=15; 45 degree flip angle [27]. There was a positive correlation between the high signal intensity, a thin triangular fibrocartilage, and positive ulnar variance. No correlation was seen between high signal intensity in the triangular fibrocartilage and age of the patient.

Perforations of the triangular fibrocartilage can be asymptomatic or posttraumatic and may demonstrate high signal intensity fluid within them on T2-weighted MR images. The asymptomatic perforations and those caused by traumatic tears present as a region of intermediate signal intensity within the triangular fibrocartilage on T1-weighted and proton density spin-echo images. The signal intensity increases on T2-weighted and gradient echo MR images. It is imperative that MR imaging of the triangular fibrocartilage be obtained with some type of T2-weighting to identify these perforations. If complete, the perforation extends to the edges of the fibrocartilage. Some tears are partial and may only extend to the superior or inferior surface. With a traumatic triangular fibrocartilage tear, fluid is usually present in the distal radioulnar joint [2]. This finding, however is not specific for triangular fibrocartilage tear and can be seen in patients with synovitis or mechanical irritation of the distal radioulnar joint.

Detection of triangular fibrocartilage tear using MRI has been investigated by Zlatkin who reported a sensitivity of 100% and a specificity of 93% in 41 patients when compared with arthrography; and a sensitivity of 89%, a specificity of 92% and and accuracy of 90% when compared with arthroscopy and arthrotomy [1]. Another study by Golimbu found a sensitivity of 93% and an accuracy of 95% in 20 TFCC TEAR patients with surgical correlation [21]. Schweitzer et al. compared MR imaging with arthrography as a gold standard in 15 patients with chronic wrist pain and found MR imaging to have a 72% sensitivity, 94% specificity, and 89% accuracy [2]. Since the triangular fibrocartilage also stabilizes the distal radioulnar joint, triangular fibrocartilage tear is occasionally associated subluxation of the ulnar head, which is well seen on axial MR images.



ULNAR IMPACTION SYNDROME

Forces in the wrist can cause the ulna and lunate to abut each other. This occurs more frequently with positive ulnar variance. With positive ulnar variance, the carpal surface of the ulna extends more distal than that of the radius, which can produce rotational contact between the ulna and lunate with subsequent perforation of the triangular fibrocartilage, lunotriquetral ligament tear, and erosion of the articular cartilage of the ulna and lunate. In some cases, MR imaging is able to detect abnormalities in the articular cartilage of these patients. In Kang´s series, MR imaging was only able to demonstrate cartilaginous abnormalities in two of the four cadaver wrists with histologically proven erosion of the articular cartilage caused by ulnolunate impaction [9]. Sclerosis and/or cysts are often found in the proximal ulnar aspect of the lunate and/or the proximal radial aspect of the triquetrium in ulnar impaction syndrome, and in our experience, may be detected on MR imaging prior to conventional radiography. The marrow demonstrates low signal intensity in areas of sclerosis and fluid-like signal intensity in areas of cyst formation on MR imaging.

DISTAL RADIOULNAR JOINT INSTABILITY

The distal radioulnar joint is formed between the semicircular convex ulnar head and the ulnar convexity in the distal radius- the sigmoid notch. Stability for this joint is provided by the interosseous membrane and to a greater extent by the triangular fibrocartilage complex.

The diagnosis of distal radioulnar joint subluxation can be difficult. Symptoms and physical exam are often nonspecific and conventional radiographs are generally unreliable. Wechsler et al. have described several methods for the diagnosis of distal radioulnar joint subluxation by CT which can also be applied to MR imaging [28].

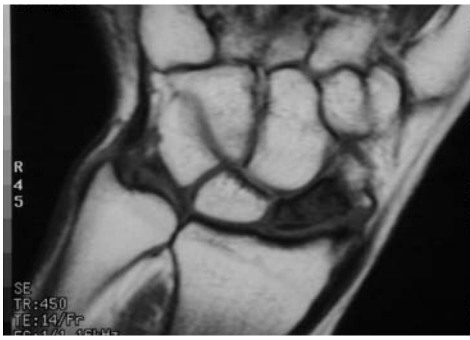
Axial images from both CT and MR imaging delineate the cross-sectional anatomy of this joint and can be used for evaluating instability. When evaluating the distal radioulnar joint on axial MR images it is important to be familiar with the small amount of subluxation that can occur with changes in wrist postioning in the normal wrist. On images of the wrist obtained in neutral position, the distal ulna articulates with the ulna in the sigmoid notch. When the wrist is pronated, the ulna moves dorsally, and when the wrist is supinated, the ulnar head moves in a volar direction. When evaluating distal radioulnar joint instability, it is optimal to include axial images of both wrists in pronation, supination and neutral positioning. These images are obtained with the arms above the patients head with the wrists placed in a head or neck coil. T1-weighted images provide a fast and accurate method for determination of distal radioulnar joint instability. MR imaging has an advantage for demonstrating soft tissue abnormalities, including triangular fibrocartilage tears, which may be associated with distal radioulnar joint instability.

FRACTURE

Although MR imaging is not used for initial diagnosis of carpal fracture, it can be used for detecting subtle or occult fractures [29]. The fracture line is typically low signal intensity on all imaging sequences with surrounding edema and hemorrhage in the marrow in acute situations, which produces low to intermediate signal intensity on T1-weighted images and high signal intensity on T2-weighting. Stress fractures can also be identified using MR imaging [30].

Multipartite carpal bones are not uncommon and can be mistaken for a fracture. The most common site for this is the scaphoid [31]. It may be difficult to distinguish multipartite carpals from true fractures with MR imaging, except if there is surrounding marrow contusion. Therefore, in the absence of surrounding marrow abnomality, a suspected carpal fracture on MR imaging should be correlated with clinical history and symptoms.

It is important to identify scaphoid nonunion which occurs commonly as a result of delayed diagnosis or when activity is resumed too soon following fracture.



SCAPHOID AVN T1

FAT SAT T2

Sequelae of nonunion include avascular necrosis and advanced degenerative arthritis. T2-weighted images are useful for detecting fracture non-union. This is diagnosed when there is increased signal intensity in the region of the fracture line caused by fluid collecting in the area of non-union. If there is no demonstration of increased signal intensity in the suspected site of nonunion, one cannot make that statement that a nonunion does not exist, as the sensitivity and specificity of this finding has not been determined. MR imaging can also be utilized for evaluation of fracture healing and for analysis of the shape of the scaphoid after the fracture has healed. CT is more generally more useful for assessment of bone graft healing.

AVASCULAR NECROSIS

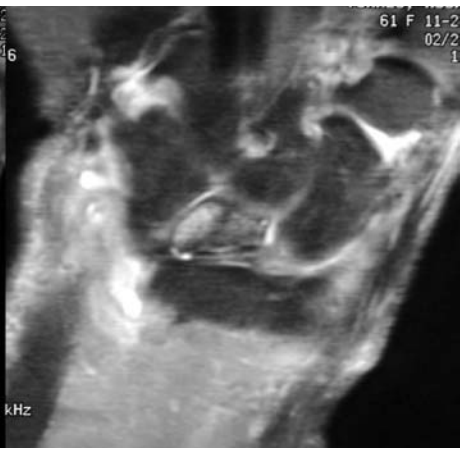
Carpal avascular necrosis (AVN) is most frequent in the proximal scaphoid. The lunate is the second most common site for carpal AVN. AVN has proved to be difficult to both diagnose and treat [32]. It is best to identify AVN early, prior to the onset of collapse and fragmentation of the bone that results in a progressive arthritic process due to loss of congruity of the joints and disorganization of the normal relationship between other intact carpal bones. MR imaging is useful for the early diagnosis of carpal AVN [33].

Scaphoid necrosis

Because the scaphoid receives its blood supply from branches of the radial artery, which enters the bone distally, fractures of the scaphoid often result in avascular necrosis of the proximal pole. Avascular necrosis can also be seen in the proximal scaphoid in patients without evidence of fracture. AVN has been reported in 16% of patients with scaphoid nonunion [34]. The presence of AVN in a proximal fragment suggests a worse prognosis for fracture healing [35]. Knowledge of AVN in the proximal fragment of a nonunion influences treatment and may result in selection of a surgical procedure such as internal fixation or bone grafting.

It can be difficult to detect early AVN in the scaphoid on conventional radiographs. Bone scintigraphy is often nonspecific. AVN of the scaphoid is easily detected on coronal MR images [35]. MR imaging can accurately predict the vascularity of the ununited scaphoid. The signal intensity can vary according the degree of fibrosis, sclerosis, and revascularization. Osteonecrosis commonly presents with low signal intensity on all MR imaging sequences. Other patterns of signal intensity in osteonecrosis have been described in the femoral head, which are also applicable to AVN in the wrist [36].

T1 KIENBÖCKS



T2 FAT SAT. NOTE THE SYNOVITIS

Kienböck´s Disease

Kienböck´s disease (also known as lunatomalacia) refers to avascular necrosis of the lunate. It is most common in males 20-40 years of age. Patients usually present with dorsal wrist pain, decreased range of motion of the wrist, and loss of grip strength. The etiology is uncertain although it has been suggested that chronic low-grade trauma is the most important factor. Kienböck´s disease is often seen in wrists with negative ulnar variance, where the ulna lies proximal to the distal radius. This configuration is believed to increase shear stress on the lunate, resulting in microfracture and necrosis [37,38].

There are four stages of Kienböck´s disease as defined by Lichtman [39]. Stage I represents an early form of Kienböck´s disease when radiographs show no evidence of avascular necrosis. In this stage, the wrist can be immobilized with reversal of the avascular necrosis [40]. In stage II, the lunate is sclerotic without evidence of collapse. Fragmentation and collapse of the lunate are seen in stage III with proximal migration of the capitate, resulting in wrist shortening. This can predispose a patient to scapholunate dissociation with disruption of the scapholunate ligament as well as carpal tunnel syndrome. In Stage IV Kienböck´s disease, the patient develops degenerative changes in the radiocarpal joint as well as subarticular cysts and carpal instability.

In our experience, MR imaging has been able to demonstrate all stages of Kienböck´s disease, including signal abnormalities, when conventional radiographs are normal. On T1-weighted coronal and sagittal MR images, low signal is seen within the lunate [41,42]. Low signal intensity is usually identified within the lunate on T2-weighted images, although early necrosis may present with intraosseous edema, hemorrhage, and hyperemia, producing higher signal intensity.

Abnormal signal intensity produced by necrosis in the lunate can be diffuse or focal. When focal, one should also consider other abnormalities, including bone island, intraosseous ganglion or cyst, or ulnocarpal impingement. Evaluation of conventional radiographs is essential to aid in characterizing the lesion.

Follow-up MR images are useful to monitor treatment of patients with abnormal signal intensity in the lunate suspicious for avascular necrosis or bone marrow edema syndrome. Following successful immobilization, the marrow signal intensity may return to normal [43]. There are many different treatments for advanced Kienböck´s disease, all having a variable success rate. If the lunate is replaced with a spacer such as a rolled tendon or prosthesis, MR imaging can be used to periodically evaluate spacer position. It can also aid in the identification of prosthesis fracture, displacement, or synovitis when a silastic implant is utilized.

TENDINOPATHY

The extensor tendons of the wrist are divided into six compartments that overlie the carpal bones and interosseous ligaments along the dorsal aspect of the wrist. The first compartment lies lateral to the radius and contains the abductor pollicis longus and extensor pollicis brevis tendons. The second compartment, lateral to Lister´s tubercle, contains the extensor carpi radialis brevis and longus tendons. The third compartment, located medial to Lister´s tubercle, contains the extensor pollicis longus tendon. The fourth compartment contains the extensor indicis proprius and extensor digitorum communis tendons. The extensor digiti minimi lies in the fifth compartment, and the extensor carpi ulnaris is located in the sixth compartment medial to the ulnar styloid. Volar to the palmar ligaments lie the deep and superficial flexor tendons of the digits and the flexor pollicus longus tendon which traverse the wrist through the carpal tunnel.

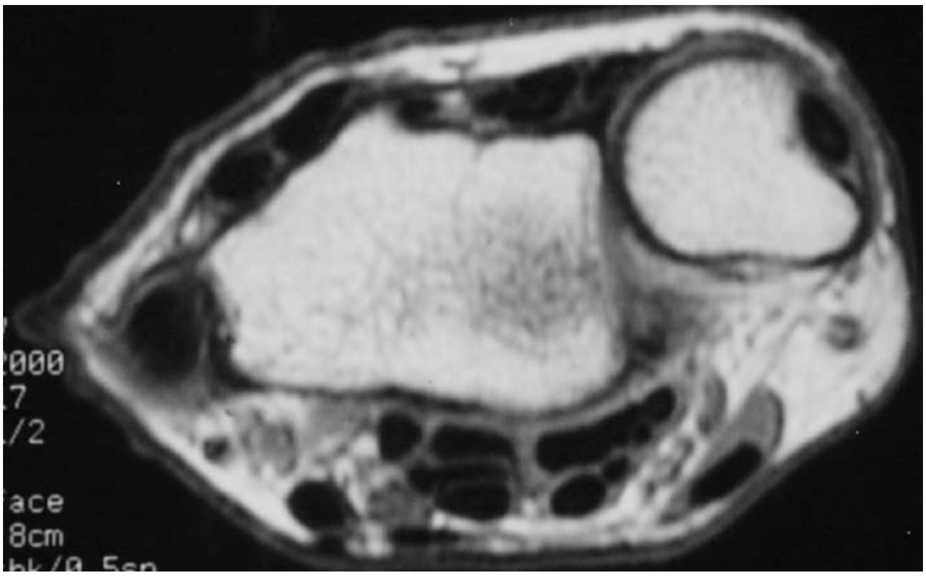
Tendinopathy is well seen on MR imaging. It may present with fluid in the tendon sheath (tenosynovitis), thickening of the tendon and/or abnormal elevation of signal intensity within the tendon on T1 and/or T2-weighted images (which may be produced by tendinitis or tear), or complete disruption of the tendon.

When evaluating tendons of the wrist, it is important to keep in mind the magic angle phenomenon, which can be seen in normal tendons if they lie approximately 55 degrees from the direction of the static magnetic field [44]. At this angle, normal anisotropic structures such as tendons may demonstrate intermediate signal intensity on short TE images. Signal intensity observed on short TE images decreases with increasing TE. Thus, increased signal intensity due to the magic angle effect may be misdiagnosed as tendinous degeneration or tendinitis.

Tenosynovitis is seen in both flexor and extensor compartments. Tenosynovitis in the sheaths of the abductor pollicus longus and extensor pollicus brevis tendons at the level of the radial styloid, DeQuervain´s syndrome, can be identified with MR imaging.

A frequent source of pain along the ulnar aspect of the wrist is tenosynovitis of the extensor carpi ulnaris tendon sheath. Subluxation of the extensor carpi ulnaris is also common and can be best demonstrated with the forearm in supination and the wrist ulnarly deviated. Inflammation of flexor tendons within the carpal tunnel is a frequent cause of carpal tunnel syndrome as discussed below.

MR imaging is useful for demonstrating the presence and extent of tendon rupture, which may be difficult to diagnose clinically [45,46]. This information can also be utilized for planning of tendon repair, relocation, or transfer. Complete tendon ruptures present as a loss of continuity in the low signal tendon. Incomplete ruptures or chronic tears are depicted by MR imaging as irregular thickening or thinning of the tendon, which may contain areas of high signal intensity on T2-weighted images. Gadolinium takes up in the area of tendon



DeQuervain´s Tenosynovitis

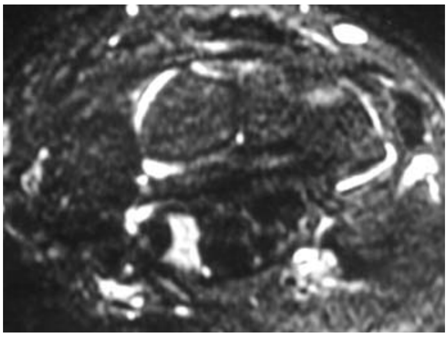
rupture, but is probably not necessary in most cases. Postoperative adhesions and scar tissue around a tendon can lead to functional impairment. MR imaging can demonstrate the low signal scar tissue around the tendon.

NERVE ENTRAPMENT SYNDROMES

Carpal tunnel syndrome

Carpal tunnel syndrome, produced when the median nerve is compressed in the wrist, is increasing in frequency with the increasing number of jobs that require repetitive motion of the wrist. Patients with carpal tunnel syndrome present with pain and tingling of the fingers along the distribution of the median nerve. Most patients with this disorder are thirty to fifty years of age. carpal tunnel syndrome is more common in females and is bilateral in up to 50% of cases [47].

The anatomic causes of median nerve compression can be assessed by MR imaging. Causes of carpal tunnel syndrome can be divided into two main categories: 1) abnormalities that compress the carpal tunnel from outside such as a mass or malalignment of osseous structures secondary to fracture, kienböck´s disease, or carpal instability producing abnormal volar narrowing and 2) increased volume within the carpal tunnel caused by



inflammation, arthritis, masses, excess fat along the dorsal aspect of the tunnel, persistent median artery, a large adductor pollicus muscle and edematous and infiltrative disorders. Flexor tenosynovitis and tendinitis resulting from repetitive wrist flexion are the most common causes of carpal tunnel syndrome [48].

MR imaging is accepted as a useful method for assessment of carpal tunnel syndrome [47,49-51]. The carpal tunnel is bordered inferiorly by the flexor retinaculum, a broad low signal intensity ligament that extends from the hook of the hamate medially to the tuberosities of the scaphoid and trapezium laterally, holding the flexor tendons in place during wrist flexion. The rigid roof of the carpal tunnel is formed by the carpal bones. The low signal intensity flexor digitorum profundus and flexor digitorum superficialis tendons lie within the tunnel as does the flexor pollicus longus tendon which lies radial to the other tendons. The tendon sheaths are intermediate signal intensity. There should only be several millimeters of distance between each of the tendons.

The median nerve is easily seen on axial MR images as a rounded or occasionally flattened structure of intermediate signal intensity. The caliber of the median nerve is relatively constant at the level of the distal radioulnar joint, pisiform, and hook of the hamate. It is usually located along the superficial radial aspect of the carpal tunnel just deep to the flexor retinaculum and anterior to the superficial flexor tendon of the index finger [49,52]. Occasionally, the nerve can lie deeper in the carpal tunnel, perpendicular to the flexor retinaculum. Patients with this normal variation are more prone to carpal tunnel syndrome. The position of the nerve can also vary between flexion and extension, and this can be observed with MR imaging [51]. Flexion of the wrist produces anatomic crowding in the carpal tunnel, seen as flattening or interposition of the nerve between the flexor tendons while wrist extension increases the distance between the median nerve and flexor tendons.

Carpal tunnel abnormalities can be visualized with MR imaging, however in our experience, the MR imaging is not always abnormal in patients with carpal tunnel syndrome. Because of the lack of sensitivity as well as the expense of MR imaging, we believe that MR imaging should be reserved for certain situations. Current clinical applications for MR imaging of carpal tunnel syndrome include (1) equivocal cases when the EMG does not correlate with clinical symptoms of carpal tunnel syndrome, (2) identification of the etiology of carpal tunnel syndrome such as an intrinsic or extrinsic mass which may obviate the need for flexor retinaculum release, (3) preoperative assessment of the position of the median nerve in patients who are scheduled for endoscopic retinacular release, and (4) postoperative assessment of patients whose symptoms recur following surgery.

In cases of tenosynovitis, MR images will demonstrate distension of the tendon sheaths. In acute tenosynovitis fluid will be seen within the tendon sheaths on MR images. Tendinitis may present as enlargement and abnormal elevation in signal intensity within the tendon. It is important to exclude the presence of a magic angle phenomenon in tendons that are high signal intensity on short TE images [44]. Tenosynovitis and tendinitis can be localized or diffuse and may be caused by overuse syndromes or an inflammatory arthropathy such as rheumatoid arthritis. Other abnormalities that can be identified by MR imaging in patients with carpal tunnel syndrome include palmar bowing of the flexor retinaculum (best identified at the level of the hamate), swelling, flattening, or attenuation of the median nerve, and elevated signal intensity within the nerve on T2-weighted images, presumably from compression-induced edema [47]. Swelling of the median nerve is often seen proximal to the level of the carpal tunnel at the level of the pisiform. With longstanding carpal tunnel syndrome, the nerve may be low signal intensity on all imaging sequences, presumably due to fibrosis. Thenar muscle atrophy may also be seen. Occasionally, muscles can hypertrophy within the carpal tunnel, particularly the lumbricals which lie distally and originate from the flexor digitorum profundus tendons. It is important to keep the fingers extended when evaluating the carpal tunnel to avoid overcalling lumbrical muscle hypertrophy since the lumbrical muscles may slip into the location of the carpal tunnel with finger flexion [50].

Recently, Sugimoto demonstrated two abnormal patterns of enhancement of the median nerve in patients with carpal tunnel syndrome following intravenous gadolinium administration [53]. Those nerves that demonstrated marked enhancement were postulated to be edematous, while those that did not enhance with contrast were thought to be ischemic. When the wrists with nerves that enhanced were flexed or extended, they often changed their pattern to a lack of enhancement. This change was associated with increase in symptoms of carpal tunnel syndrome. The authors concluded that carpal tunnel syndrome may result from a circulatory disturbance.

Carpal tunnel syndrome is usually treated conservatively with splinting and medication. If symptoms continue despite conservative treatment, the flexor retinaculum is surgically released. This can be done as an open procedure or by blind endoscopic release. Since the endoscopic technique is done with a limited field of the view, the nerve is more prone to injury. Following successful carpal tunnel release, the flexor retinaculum and contents of the carpal tunnel are volarly displaced.54 MR imaging can be utilized following surgical decompression for those patients who are symptomatic to assess for incomplete retinacular release or reattachment, scarring in the region of the carpal tunnel, neuritis of the median nerve, or development of a neuroma, which can occur when the median nerve is inadvertently cut [47].

Guyon´s Canal Syndrome

MR imaging can reliably demonstrate the area of Guyon´s canal [55]. It is in this fascial tunnel that the ulnar nerve enters the palm from the forearm and extends distally from the level of the pisiform where it divides into two sensory branches as well as the deep motor branch. Guyon´s canal extends approximately four centimeters from the palmar carpal ligament at the proximal edge of the pisiform to the origin of the hypothenar muscles at the level of the hamate. Besides the ulnar nerve, the ulnar artery and occasional veins pass through this region and there is abundant adipose tissue surrounding these structures which allows them to be well visualized by MR imaging.

The deep motor branch of the ulnar nerve is subject to compression by repetitive motion, adjacent masses such as ganglia, lipomas, and anomalous muscles compressing the canal, ulnar artery false aneurysm, hypertrophy of the flexor carpi ulnaris tendon, hypertophy of the palmar carpal ligament, osteoarthritis of the pisiform-triquetral join, or fractures at the bases of the metacarpals, hook of the hamate, and pisiform [54-59]. MR imaging can reliably demonstrate surrounding masses as well as anomalous muscles.

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