Pain Physician. 2004;7:149-160, ISSN 1533-3159

A Focused Review

The Fundamentals of Musculoskeletal Imaging

Joseph D. Fortin, DO, and Edward C. Weber, DO

Pain management physicians need to understand the basic diagnostic tools for their profession, including the major musculoskeletal imaging modalities for joint and muscle disorders. This article serves to review the indications and limitations for musculoskeletal imaging modalities with particular attention to how altered anatomy may reflect injury mechanisms.

Key words: imaging, musculoskeletal, MRI, CT and biomechanics.

Imaging studies represent a key diagnostic tool for the pain management physician, yet the lack of concerted exposure to these modalities in pain management training programs is widely recognized.

This article attempts to partially fill the aforementioned knowledge gap by describing the basic principles of applying the major musculoskeletal imaging modalities to joint and muscle disorders. The focus will be specific, common pathologic findings on MRI with some CT, plain film and arthrography correlates.

Integrating Structure and Function in Musculoskeletal Imaging

Since joints are mechanical structures, consider the joint mechanics to plan your approach to imaging interpretation (1, 2). Consider the shoulder joint, which allows rapid multidirectional movement while maintaining the "ball in the socket." Many glenohumeral abnormalities coincide with the discrepancy between great movement potential and limited innate stability. For example, can the rotator cuff tendons glide uninterrupted? Is there evidence of myotendinous strain? Are there footprints of asymmetric loading, subluxation, or dislocation (e.g., labral tears, chondral, or osseous defects)? Could congenital variances jeopardize normal joint mechanics (e.g., hooked acromion or unusual labral configuration)?

Indications for Musculoskeletal Imaging Modalities

Radiography

The spatial resolution of transmission radiography provides a unique perspective on bone morphology (Fig. 1) and texture. Plain films still fulfill a basic role within our diagnostic armamentarium for screening trauma cases when ruling out instability, examining for benign bone conditions such as, heterotopic ossification and providing a comparative or complimentary study to magnetic resonance imaging (MRI) and computerized tomography (CT).

Fig 1. *Oblique radiograph demonstrates large osteochondroma arising from the deep surface of the scapula in a patient with multiple osteochondromas (note wavy contour of humeral shaft and the osteochondroma projecting over the acromioclavicular joint). It would be difficult to gain this perspective on the relationship between the scapular osteochondroma and the rib cage with cross-sectional imaging.*

Computerized Tomography (CT)

CT still has higher spatial resolution than MRI, for better definition of fractures (Fig. 2) (specifically cortical abnormalities) and other bone morphology. Conversely CT is clearly inferior to MRI for soft tissue contrast resolution and marrow space changes (e.g., early stress fractures).

Fig 2. *Sagittal reconstruction image from helical CT scan of the lumbosacral spine vividly demonstrating an L4 pars intra-articularis fracture.*

From Spine Technology and Rehabilitation and The Imaging Center, Fort Wayne, IN. Address Correspondence: Joseph D. Fortin, DO, Spine Technology and Rehabilitation, 7230 Engle Road, Suite #210, Fort Wayne, IN 46804.
E-mail: fortin@pol.net
Funding: There was no outside financial support for this project.
Conflict of Interest: None

Ultrasound

Ultrasound allows assessment of myotendinous disorders during provocative maneuvers (which may elicit symptoms and elucidate the diagnosis). Although the potential for powered doppler and ultrasound contrast mediums have not come to fruition (at present) – the potential for this dynamic modality is exciting. Ultrasound remains limited by being operator dependent and a having a small field of view with poor soft tissue contrast (1, 2).

Scintigraphy

Radionuclide scanning is very sensitive for AVN, occult fractures and most osseous tumors. Unfortunately, it is etiologically nonspecific. An example is a child who is limping and has a tender area on palpation with a positive radionuclide scan. The area of increased tracer uptake may be tumor or a healing stress fracture rather than an infection. Moreover, bone scans will remain positive for long periods of time after an infection has been eradicated and may be falsely negative with multiple myeloma and other lytic tumors (e.g., renal or thyroid).

MRI

MR is the study of choice for evaluating muscle and tendon injuries as well as, evaluating marrow space changes as in early stress fractures. Indications for MR imaging include: 1) To determine the severity and extent of injury in a high performance athlete or worker; 2) To provide prompt diagnosis when it is crucial for initiating treatment; 3) To evaluate uncommon sources of muscle or joint pain (e.g., intermittent muscle herniation through a fascial rent, metabolic and inherited muscle disorders, mass lesions, and severe cases of delayed onset muscle soreness); 4) To define a soft tissue mass in a patient without a clear history of trauma; and 5) To provide optimal definition of marrow space abnormalities.

Technical Aspects of Musculoskeletal MRI Imaging

Skin Marker

A marker is applied over any palpable mass or focal area of tenderness (region of interest).

Patient Positioning

If the posterior compartment is the region of interest, prone positioning of the patient should be considered – since posterior structures may be compressed (possibly deforming an important lesion, muscles, or obscuring intermuscular fat planes).

Coils

Coil selection (e.g., surface, body, head, shoulder, or knee coils) depends on the desired field of view and spatial resolution as well as the patient's body habitus.

Imaging Planes

Sagittal and coronal images are used to delineate the longitudinal extent of myotendinous abnormalities and contusions as they usually approximate the long axes of muscles. Axial images are the best way to quickly examine the relative interrelationships of a specific finding in a medial to lateral and anterior to posterior perspective.

MRI Pulse Sequences

Knowing the strengths and limitations of each pulse sequence is essential for proper planning of an MRI examination as well as the interpretation (3). T1 weighted pulse sequences provide the best depiction of anatomy and marrow space abnormalities. T2 weighted pulse sequences provide excellent soft tissue contrast at the expense of poor signal to noise ratio. Proton density images, like T1, provide a good "look" at the anatomy but suffer from lack of contrast. Combined with fat suppression, "black stuff" (menisci, ligaments, and tendons) will be enhanced – although contrast resolution will diminish even more. Gradient echo images have an excellent signal to noise ratio per unit time yet are prone to magnetic susceptibility artifact which obscures some pathology while exaggerating others. Three-dimensional Fourier transformation (3DFT), gradient echo uniquely allows for very thin contiguous sections yet have poor soft tissue contrast. While fast spin echo is four times quicker than conventional T2 weighted pulse sequences the images tend to suffer from blurring and yield high signal from fat. Fat suppression combined with fast spin echo eliminates the latter problem while increasing the sensitivity to changes in free water. STIR pulse sequences are excellent for marrow space abnormalities but have poor signal to noise ratio and anatomical plane distinction is poor (secondary to loss of fat signal). It is also difficult to differentiate tumor versus perineoplastic edema on STIR. However, STIR images make pathology more conspicuous due to the additive T1 and T2 contrast. Hence, a fast STIR sequence is often used to locate a lesion while fast spin echo T2 is applied secondarily to look at the lesion's morphology.

IV gadolinium can be used to exclude neoplastic or inflammatory conditions while gadolinium arthrography accurately depicts loose bodies, ligaments, menisci and intraarticular tendons.

Soft Tissue Injuries and MRI

Compartment Syndrome

Although compartment syndrome is most often seen in the lower extremity below the knee it can involve any muscle compartment, including the thigh, forearm, and paraspinal musculature (4). The diagnosis of compartment syndrome is primarily based on history and physical examination as MRI findings are non-specific. The MRI findings depend on when the examination is obtained in relationship to the injury since signal intensity alterations reflect the phases of hemoglobin degeneration (as noted below). Findings characteristic of chronic compartment syndrome, which has a proclivity for the peroneal compartment, include high T1 signal from fatty replacement and low T1 and T2 signal from dense fibrosis. Compartment syndrome or rhabdomyolysis (muscle infarction) may progress to calcific myonecrosis presenting as a low signal calcific shell surrounded by a cavity filled with high T2 signal of liquified necrotic muscle. Peroneal nerve damage may result from pressure necrosis.

Lacerations

Acute lacerations demonstrate high T2 signal owing to hemorrhage and edema as well as sharply marginated discontinuity of the involved fibers. Over time lacerations will demonstrate low T1 signal secondary to fibrosis and, in some cases, high T1 signal intensity secondary to fatty replacement.

Acute blood yields low signal on T1 and T2 weighted images secondary to deoxyhemoglobin. Subacute hematomas demonstrate high signal on T1 due to formation of methemoglobin. Re-concentration of methemoglobin is usually highest at the periphery of the hematoma-producing a high signal T1 "rim." Early subacute blood discloses low signal on T2 weighted images. Late subacute and chronic hematoma yields high T2 signal.

A chronic hematoma results in hemosiderin which is low signal on all pulse sequences. Hemosiderin is most striking on gradient echo pulse sequences owing to magnetic susceptibility (artifact).

Contusions

These manifest as high signal on T2 (preferably fat suppressed) and STIR associated with a feathery, infiltrative appearance and no laxity or fiber discontinuity.

Strains

When the muscle tendon unit fails it occurs most commonly at the myotendinous junction. Consider the muscles which cross two joints and have a high proportion of fast twitch fibers such as the hamstrings, rectus femoris, gastrocnemius, and paraspinal musculature when searching for a muscle strain as these muscles are most prone to injury from excessive stretch or tension. It is important to remember to closely inspect the associated tendons as tendinosis (or tendon degeneration) is considerably more common than strain.

Grade I or Mild Strain

Grade I or mild strain results in no significant loss of strength or range of motion and consequently no architectural distortion is identified on MRI. MR findings consist of high T2 signal intensity and perhaps a band of perifascial fluid.

Grade II or Moderate Strain

Grade II or moderate strain results in partial fiber disruption and partial loss of strength. The amount of high T2 signal intensity reflects the extent of edema, inflammation, fiber discontinuity and/or hemorrhage.

Complete myotendinous disruption or severe strain results in loss of strength and sometimes tendon retraction (Fig. 3). MRI will demonstrate complete discontinuity of fibers (often with a hyperintense T2 fluid collection in the gap) as well as associated edema and hemorrhage.

Fig 3. *Sagittal fat suppressed T2 fast-spin echo MR scan demonstrates complete tear and retraction of the triceps tendon.*

Delayed Onset of Muscle Soreness

A history of unaccustomed exertion, usually from eccentric contraction as downhill hiking or running, is accompanied by muscle soreness, which peaks at 2-3 days and subsides within a week. MRI demonstrates reversible structural damage at a cellular level as abnormal T2 signal intensity. Signal changes may remain for up to 80 days post injury. Exertional rhabdomyolysis, perhaps a severe form of DOMS, can cause irreversible muscle necrosis (4).

The above traumatic disorders must be distinguished from inflammatory, vascular, neoplastic and primary myopathic disorders.

Imaging Low Signal Structures on MRI

Tendons, ligaments, labrum, and menisci all yield both low T1 and T2 signal. Consequently, when examining these structures for pathology one should exclude the presence of high signal intensity or mixed signal changes within their substance. Tendon degeneration will present as thickening or attenuation, waviness and laxity. Associated tendon sheath and joint fluid is often present. Complete tendon tears will demonstrate a characteristic fluid filled gap or defect. Muscle strains often accompany tendon injuries. Corticosteroid injections may confuse the diagnosis of myotendinous strain as STIR and T2 pulse sequences can show increased signal for one month following the injection. Articular cartilage has three layers with variable signal intensity.

Entrapment Neuropathies

Nerve entrapment syndromes are optimally evaluated on axial MRI sections by employing T2 and STIR images which demonstrate increased signal intensity within the muscles innervated by the nerve. Search for any pathology which may compromise the normal dimensions of the nerve tunnels for example: 1. A thickened cubital tunnel retinaculum or anomalous anconeus epitrochlears as in ulnar nerve entrapment, 2. Ligament of Struthers or supracondyloid spur when considering medial nerve entrapment, 3. An inflamed radial bicipital bursa impinging the posterior interosseous nerve, 4. Thickening of the arcade of Frohse in radial nerve entrapment, and 5. Ganglion cyst, heterotropic ossification, tumors, displaced fracture fragments, and associated ligament thickening are other possible causes.

Glenohumeral Joint

Rotator Cuff Injuries

Because of the oblique orientation of the shoulder girdle in relationship to the conventional anatomical planes, sagittal and coronal images are typically acquired in an oblique fashion. The major plane of interest for rotator cuff injuries is the coronal/oblique plane.

Full thickness tears show high T2 signal from the articular to the bursal side. Within any full thickness tendon tear the imager must search for tendon retraction. Coronal/oblique and sagittal/oblique images usually demonstrate that the leading edge of the supraspinatus is the initial site of disruption.

Subscapularis tendon tears are best viewed on transaxial sections and can be seen next to the lesser tubercle. Always inspect for other cuff tendon tears and exclude medial displacement of the bicipital tendon from its groove. Also look for associated labral tears, in the setting of rotator cuff tear as supraspinatus dysfunction may lead to anterosuperior glenohumeral instability - the so called SLAP lesion (supraspinatus labral instability pattern) (1).

The outer portion of the supraspinatus tendon may appear intermediate (versus low) signal in normal individuals, masquerading as mucinous or myxoid changes (as noted in tendinosis or tendinopathy).

Partial thickness tears yield high T2 signal within the substance of the supraspinatus tendon. "Rim-rent" tears involve the articular side of the supraspinatus tendon at the greater tuberosity insertion, occur more commonly in young patients and may be related to angulation of collagen fibers inserting on the greater tuberosity. MR arthrography can be helpful except bursal sided partial tears are undetected by this method.

Impingement Syndrome

Impingement syndrome can occur externally on the subacromial or subcoracoid side or internally involving the posterior superior portion of the rotator cuff tendons.

MRI may provide imaging/ anatomical footprints of impingement but the diagnosis must ultimately be an extension of the history and physical examination. Although MR arthrography and imaging in the abduction and external rotation (ABER) position improve the yield for internal impingement syndrome, most studies are not conducted with the shoulder in the impingement position and obviously the relationship of the involved structures change with movement. Moreover, most dedicated extremity MRI units are too small for imaging the shoulder or hip (field of view 16 cm with a maximal acceptable extremity circumference of 38 cm) (3).

MR findings suggestive of impingement include: 1) Subacromial enthesophyte (also visible on plain film); 2) A hooked acromion (versus flat or concave) this is best imaged in the sagittal plane, the shape may result from a subacromial enthesophyte; 3) An inferior sloping acromion; 4) Thickening of the coracoacromial ligament (2).

Shoulder Instability

Glenohumeral instability is dependent on two factors: 1) An effective glenoid arc (which supports the humeral head); 2) Humeral joint reaction forces (i.e., forces applied to humeral head).

There is no consensus regarding a gold standard MRI technique yet there are myriad of pitfalls of all protocols: 1) Varying configuration of the labrum (although usually triangular); 2) Alterations in signal intensities secondary to magic angle phenomenon or tissue degeneration; 3) Normal anatomy, which can simulate pathology in some sections (glenohumeral ligaments, synovium, and biceps tendon). A common scenario where normal anatomy simulates pathology is the bicipital tendon attachment at the anterior superior labrum. The transitional zone between the labrum and articular cartilage yields intermediate signal intensity which may simulate a tear. Conversely, there is consensus that the introduction of contrast material into the glenohumeral joint (CT-arthrography or MR-arthrography) enhances glenohumeral joint ligament visualization as well as lesions specific to the unstable shoulder as noted below.

Fig 4. *Shoulder MR arthrogram. Axial fat suppressed T1 fast-spin echo MR sequence demonstrates Bankart lesion in patient with normal radiographs, but clinical signs of anterior instability.*

While transaxial scans are most essential for evaluating instability, coronal/ oblique and sagittal/oblique scans are necessary for complete analysis of the ligaments on MRI. Learning how the osseus, ligamentous, and tendinous anatomy relates to the glenoid margins when viewed as a clock (specifically 11 to 3 o'clock and 3 to 6 o'clock positions) is fundamental for understanding instability lesions.

Specific Shoulder Instability Lesions

Bankart

The anterior band of the inferior glenohumeral ligament avulses the anterior inferior labrum and adjacent scapular periosteum (Fig. 4). The labrum and ligament may have a floating appearance in the glenohumeral joint or create an ovoid mass (a.k.a. GLOM).

ALPSA (Anterior Labroligamentous Periosteal Sleeve Avulsion)

This entity is similar to the Bankart lesion except the periosteum is intact and the inferior glenohumeral ligament rotates inferomedially.

HAGL (Humeral Avulsion of Glenohumeral Ligaments)

The glenohumeral ligament avulsion occurs on the humeral not the labral/ glenoid side in this instance. This syndrome is more prevalent in the elderly population.

SLAP (Superior Labral, Anterior and Posterior tear)

This peculiar variety of labral injury is seen in overhead arm motion athletes, related to traction of the biceps tendon and/or glenohumeral ligament.

Bennett Lesion

An odd boney excrescence forms on the posterior aspect of the glenoid cavity. Theories regarding it's origin include: 1) Traction of the posterior band of inferior glenohumeral ligament; 2) Traction on the joint capsule; 3) Traction on the triceps tendon. The Bennett's lesion most likely begins as an inferior glenohumeral ligament enthesophyte.

Denticulate Glenoid

Congenital hypoplasia of the glenoid leads to instability (1).

Imaging of the Elbow

Similar to other musculoskeletal regions new MRI surface coil designs, pulse sequences, and clinical experience have elevated this modality to the overall gold standard for assessing soft tissue and marrow space pathology (15, 18, 20, 21).

The elbow is typically scanned with the patient in a supine position while the arm is at the side.

STIR sequences are used for locating pathology due to the additive effect of T1 and T2 contrast, a characteristic unique to this pulse sequence. STIR sequences are acquired in the coronal planes and T2 images are obtained in the axial and sagittal planes. Axial MRI scans of the elbow in flexion may be used to disclose medial dislocation of the ulnar nerve or dislocation of the medial head of the triceps.

Valgus Stress Injuries

These injuries may occur at the result of medial tension and/or lateral compression overloading from a single event or chronic repetitive microtrauma. MRI allows the differentiation of these mechanisms. Medial tension overload results in strain of the flexor/pronator muscles, sprain of the ulnar collateral ligament and often form a traction spur. Ulnar neuropathy can also result from medial tension strain. Lateral compression overloading may produce degenerative arthritis, osteochondral loose bodies, and osteochondritis dissecans of the capitellum or radial head.

Medial Collateral Ligament Injuries

These injuries are common in throwing athletes with or without common flexor injury. The anterior bundle of the MCL complex is most commonly involved and can be detected, localized and graded with high quality MRI imaging.

As partial detachment of the deep undersurface fibers are invisible by open surgical approaches, MRI imaging is paramount for detection. Intraarticular gadolinium or CT arthrography will enhance the diagnostic yield. Partial detachment will be characterized by distal extension of contrast along the medial margin of the coronoid.

Although complete distal or proximal avulsion occurs, mid-substance ruptures account for the majority of MCL tears. As the flexor digitorum superficialis is invested in the anterior bundle of the MCL, a flexor digitorum superficialis strain must be excluded in the setting of MCL injury. Lateral compartment bone contusion may also occur in association with acute MCL tears. Traction spurs are particularly common in baseball pitchers due to repetitive valgus stress. Chronic MCL degeneration is characterized by ligament thickening and focal calcification (19).

Medial Epicondylitis

This condition, also known as golfer's elbow, pitchers elbow, or medial tennis elbow results from common flexor tendon degeneration from flexor/pronator overloading. MRI will demonstrate tendinosis and muscle strain. The STIR pulse sequence is particularly sensitive for depicting both muscle and marrow space changes. In young baseball players so called little leaguers elbow may occur if the medial epicondylar apophysis incurs a stress fracture, avulsion, or delayed closure. MRI will demonstrate changes in boney configuration and marrow space or adjacent soft tissue edema.

Lateral Epicondylitis and Lateral Ulnar Collateral Ligament Injury

Tennis elbow involves degeneration and tearing of the common extensor tendon. Most often the extensor carpi radialis brevis is partially torn in lateral epicondylitis, manifesting as abnormal increase in intratendinous signal. While partial tears are characterized by thinning, complete tears are identified by a fluid filled gap between the tendon and the remaining portion on the boney attachment site. Ulnar collateral ligament injury should also be suspected with any lateral elbow pain especially if the patient has a history of posterolateral rotary instability. (ROSS) Lateral collateral ligament injuries are commonly associated with common extensor tendon tears (Fig. 5). Radial nerve entrapment may also accompany lateral epicondylitis, although in isolation it can masquerade as lateral epicondylitis (19).

Biceps and Triceps Tendon Injuries

Biceps tendon ruptures are relatively uncommon. They can occur in weight lifters and heavy manual laborers. The clinical diagnosis may be difficult as the aponeurosis (lacertus fibrosis) will remain intact with minimal muscle tendon and muscle retraction. MRI will detect the extent of tearing, as well as the size and location of the gap which is critical for preoperative planning. Distal biceps tendinosis is common as a vulnerable blood supply exists 1 cm from the radial tuberosity attachment exist. Moreover, the hypovascular zone may be impinged between the radius and ulna upon pronation. The bicipital radial bursa may become inflamed in association with bicipital tendinosis. IV gadolinium will differentiate an inflamed cyst or bursa versus a solid neoplasm. T2 weighted axial images are most diagnostic for bicipital tendon pathology and should be acquired from the myotendinous junction to the radial tuberosity insertion (2).

Triceps tendon ruptures are rare and

Fig 5. *Coronal T2* fat suppressed gradient echo sequence demonstrating complete tear of the lateral collateral ligament of the elbow in association with avulsion of the common extensor tendon.*

partial tears are considered by some to be even less common. Local steroid injections and anabolic steroid abuse have been implicated in triceps tendon ruptures. Olecranon bursitis may accompany triceps tendon tears or conversely may mimic them.

Bone Injuries

Bone injuries are more conspicuous on T1 weighted, fat suppressed T2 weighted and STIR pulse sequences (21).

Anterior capsular avulsion and anterior coronoid process contusion or fracture can result from posterior elbow dislocation or subluxation – as a consequence of hyperextension. Common accompanying injuries include brachialis muscle strain, medial, and lateral collateral sprains.

Chronic lateral impaction, as noted in adolescent pitchers and gymnasts, can lead to osteochondritis desiccans of the capitellum. Medial overloading (of the flexor/pronator muscle group) can cause laxity of the MCL (as seen in throwing athletes) leading to incongruity between the olecranon process and fascia as well as secondary loose body formation. Unstable osteochondral fragments, from either lateral or medial mechanisms, are most readily identified on T2 weighted images (21). When there is no evidence of joint effusion on exam or on plain films consider saline or gadolinium arthrography as small loose bodies may be difficult to exclude on conventional MRI imaging. The classic MRI appearance is fluid encircling the fragment.

Extension overloading, for example by the triceps muscle on the olecranon of an adolescent baseball pitcher, can lead to olecranon physeal plate fracture. When plain films are equivocal MRI imaging will distinguish an ossified versus an unossified epiphyseal cartilaginous plate.

Imaging of the Wrist

MRI has eclipsed other diagnostic modalities in imaging the wrist as it allows direct visualization of bone marrow and hyaline cartilage in addition to superior depiction of muscle, ligaments and tendons (15).

The wrist must be scanned in a comfortable position to avoid motion artifact - typically with the arm at the side in a supine position. Supination can be used when radioulnar instability is suspected. T1 weighted images are acquired in the sagittal and coronal planes. T2 weighted axial pulse sequences are obtained as well as coronal STIR and gradient echo. 3-D gradient echo sequences can be used when very thin contiguous axial sections may assist in the diagnosis, however they have relatively poor soft tissue contrast compared to spin echo techniques. Fat suppression will enhance the visualization of hyaline articular cartilage and marrow space changes while diminishing chemical shift artifact at the cortical/bone fatty marrow interface. Intraarticular dilute gadolinium or saline may be used to detect ligamentous or triangular fibrocartilage disruption and to visualize loose bodies.

Avascular Necrosis and Occult Fractures

MRI has a high sensitivity for revealing avascular necrosis and occult fractures. AVN most commonly involves the proximal scaphoid pole and less commonly the lunate bone (i.e., Kienbock's). Kienbock's disease is often associated with negative ulnar variance where the ulna is short resulting in abnormal stress on the lunate. Although radionuclide scanning is excellent in screening for AVN or occult fractures, it is non-specific. AVN will manifest as conspicuous low signal intensity on T1 weighted pulse sequences, in contrast to the usual high signal from fatty marrow. Conversely, high signal intensity will be revealed on STIR and T2 weighted images resulting from marrow edema particularly in early AVN. MRI plays an important role in the detection of occult fractures, especially a radio-graphically negative scaphoid fracture when early diagnosis and treatment may prevent nonunion.

Triangular Fibrocartilage Complex

The TFCC aids in stabilizing the distal radioulnar joint while cushioning the ulnocarpal mechanism. In the past, plain film arthrography was the mainstay of diagnosis, however, benign arthrographic communication across the TFCC occurs in 7-35% of asymptomatic individuals. The diagnosis can be achieved in 90-95% of cases non-invasively with MRI. Like knee meniscal tears, TFCC tears appear as linear cleavage or gaps of increased signal intensity on coronal MRI images. Many radiologists use the Palmer system for classification of TFCC pathology.

Ulnolunate Impingement Syndrome

This phenomenon results from positive ulnar variance involving the ulnar portion of the lunate versus Keinbock's disease with negative ulnar variance involving the central aspect of the lunate. Ulnolunate syndrome results from direct impaction of the ulna and lunate with typical findings of subchondral sclerosis and cartilage erosion, TFCC perforations and lunotriquetral ligament rents.

Carpal Instability

The intercarpal ligaments are optimally visualized in the coronal plane. The most common syndromes resulting in malalignment of the carpal bones from tearing of intrinsic intercarpal or extrinsic volar ligaments include VISI (volar intercalated segment instability) and DISI (dorsal intercalated segment instability) deformity. Coronal MRI images can distinguish volar tilting of the lunate bone with a lunotriquetral ligament tear from dorsal lunate tilting with a scapholunate ligament tear. Although MR arthrography can improve the sensitivity of conventional MRI imaging, arthroscopy is necessary to diagnose these conditions in some cases. Parenthetically, carpal tunnel syndrome can result from volar displacement of the lunate in either VISI or DISI deformities.

Tendinopathy

MRI is the imaging modality of choice in characterizing tendon pathology. As previously noted normal tendons will demonstrate low signal on all pulse sequences, consequently increased tendon signal intensity indicates pathology. Tendinosis, rupture or partial tearing of tendons in the hand and wrist are best depicted on T2 weighted sequences. Common wrist tendinopathy includes DeQuervain's stenosing tenosynovitis, (involving the abductor pollicis longus and extensor pollicis brevis tendon), flexor tendon sheath inflammation (associated with carpal tunnel syndrome) and extensor carpi ulnaris tenosynovitis (resulting in ulnar wrist pain).

Carpal Tunnel Syndrome

MRI findings of carpal tunnel syndrome include: 1). Increased signal intensity of the median nerve on T2 weighted images (which is usually intermediate signal intensity), 2). Swelling of the median nerve at the pisiform level, and 3). Attenuation of the median nerve at the hamate level and Palmar bowing of the flexor retinaculum.

Gamekeepers or Skier's Thumb

Gamekeepers thumb or skier's thumb are terms used interchangeably to describe ulnar collateral ligament injury of the MCP thumb joint (17). Although this lesion can be appreciated by routine provocative physical exam maneuvers, it is important to differentiate from the lesser known subset in which the torn UCL is dislocated superficial to the adductor aponeurosis (i.e., Stener lesion). Standard clinical examinations and stress radiography are unable to differentiate gamekeepers from Stener lesions. MRI accurately demonstrates dislocated UCL ligaments.

Hip Joint

The hip is a ball and socket type joint which is built for stability while allowing ample degrees of freedom for gait mechanics and activities of daily living. It has a substantial acetabular rim as well as strong ventral ligaments. Common hip pathologies relate to repetitive overloading in a weight bearing position, direct trauma, the many tendon attachments and apophyses as well as its' vulnerable blood supply.

Technical considerations for MRI imaging of the hip include use of a body coil or phased array torso coil, which is dictated by the size of the hips and pelvis. A typical protocol may consist of a coronal fast inversion recovery localizer, T1 coronal and sagittal, as well as axial fast spin echo T2 pulse sequences (5).

Avascular Necrosis

The femoral head is the most frequent sight of AVN. Both hips should be imaged, as AVN is bilateral in up to 50% of all cases. Although AVN is idiopathic, in up to 1/3 of all cases, the diagnosis should be considered in any symptomatic patient with the following history: a subcapital displaced fracture/dislocation, steroid use, ethanol use, status post renal transplantation, status post irradiation therapy, or a history of pancreatitis, sickle cell disease and dysbaric exposure.

MRI is unquestionably the most sensitive modality for detecting AVN (5, 6). The earliest MRI finding is non-specific marrow edema which may be indistinguishable from idiopathic bone marrow edema (see section below).

Over time vascularized granulation tissue at the edge of the reactive bone contrasts with thickened trabeculae to produce a "double line" on T2 weighted images (with high and low signal respectively). A subchondral fracture, occurring after the lysis/sclerotic phase, presents as an arc of high signal (or crescent sign on x-ray). Finally, the collapse of the articular surface results in incongruity between the femoral head and the acetabulum. Collapse will seldom occur if less than 50% of the femoral head is involved. Greater than 75% of femoral head involvement portends a poor prognosis, in terms of collapse.

Hip Bone Marrow Syndromes

There are three major syndromes involving marrow space edema of the hip including: 1) Transient osteoporosis of the hip; 2) Regional migratory osteoporosis; 3) Transient bone marrow edema syndrome. These syndromes are enigmatic and poorly understood. It is important to exclude AVN, bone contusion, osteomyelitis and infiltrative neoplasm.

Transient osteoporosis of the hip (TOH) was originally described in pregnant women with proximal femoral focal osteoporosis (on x-ray) and hip pain. Regional migratory osteoporosis involves multiple joints, which are sequentially affected. Transient bone marrow edema syndrome is self-limiting. In contrast to AVN, MRI signal changes dissipate in several months (6).

The edema manifests as low T1 and high T2 signal on MRI. In all three conditions the edema involves the head and neck, is homogenous and well demarcated. The intertrochanteric regions are variably involved.

Hip Trauma

MRI is very sensitive for radiographically negative hip fractures. Traumatic fractures appear as oblique or wavy low signal lines (both on T1 and T2). The surrounding edema yields high T2 and low T1 signal.

Fatigue or stress fractures may show only focal edema before progressing to a low signal fracture line. Fatigue fractures involve the femoral neck, while insufficiency fractures have a proclivity for cancellous, sacral and pelvic ring bone. STIR pulse sequences are excellent for demonstrating marrow space edema. CT has a role in some situations for delineating subtle cortical and trabecular disruption.

Hip Arthritis

As osteoarthritis or degenerative joint disease is associated with asymmetric loading, a unilateral or asymmetric presentation is most common.

Cartilage is difficult to directly visualize but arthrography and MRI techniques, which give an arthrography like effect (fat suppression T2 and gradient echo), help reveal chondral defects. Newer techniques (beyond the scope of this discussion) are aimed at directly improving cartilage constituent changes: magnetization transverse contrast, delayed indirect MR arthrography and spectroscopy (resolving spectral components of cartilaginous signal). On conventional pulse sequences (especially fat saturation proton density/T2), look for chondral defects, subchondral cysts and osteophytes.

MRI arthrography is the gold standard for labral tears which may have associated supra or peri-acetabular soft tissue and advanced degenerative joint changes.

A rapidly destructive form of osteoarthritis has been described which can mimic septic or rheumatoid arthritis. MRI findings include a large effusion, marked loss of cartilage, subchondral bone resorption and normal marrow space signal.

Tendon Avulsions

Avulsion injury of the hip and pelvis should be suspected in any young patient with a history of trauma and pelvic girdle pain, as there are many apophyses about the hip and pelvis. The single most common site of avulsion in the body is the ischial apophysis (puberty to age 25 when it fuses). Always search for multiple avulsions since these occur in 1/3 of all patients.

Imaging the Knee

Anterior Cruciate Ligament (ACL)

Understanding the anatomy and mechanism of injury allows the imaging protocol selection and an appreciation of the findings. For example, axial, coronal and sagittal images are necessary for complete evaluation of both ACL bundles (anteromedial and posterolateral) due to an oblique course through intercondylar notch. T2 images are especially important as they best detect incomplete tears (which have a prevalence of 10-20%; and

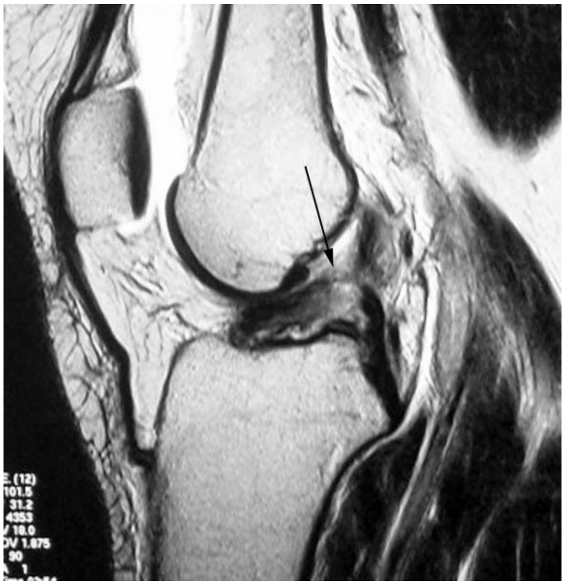

Fig 6. *Sagittal T2 fast-spin echo MR image demonstrates complete mid-substance tear of the ACL.*

most often involve the posterolateral bundle) (7).

The rotary nature of acute injuries and the oblique anatomy may lead to associated arcuate complex or posterolateral muscle damage. Lateral compartment bone contusions may result from traumatic anterior subluxation of the lateral condyle impacting the posterolateral tibial plateau (10).

ACL mid-substance rupture is usually easily recognized by an MRI as an obvious interruption of it's usual intercondylar course (Fig. 6).

ACL avulsions may occur at the femoral or tibular attachment. Femoral avulsion is best viewed on axial and coronal scans to distinguish it from more common mid-substance tears. Tibial avulsions occur more commonly in the skeletally immature. Tibial avulsion is best identified on coronal and sagittal MRI planes.

"Soft signs" of ACL insufficiencies include anterior translation or subluxation of the tibia on the femur (which is especially a helpful sign when a chronically torn ACL has fibrosed to the PCL) or posterior sloping of the ACL on the sagittal imaging.

Patient's who have recurrent knee pain that is status post ACL reconstruction the following pathology must be excluded: 1) Graft rupture; 2) Graft impingement on the intercondylar roof; 3) Tibial tunnel ganglion cyst and; 4) Focal arthrofibrosis at the anterior margin of the ACL the so called cyclops lesion).

Meniscal Tears

Vertical or peripheral tears are often associated with ACL ruptures and are easily overlooked (Fig. 7). They are found in the posterior horn of the lateral meniscus most often. "Pseudotears" from the adjacent lateral popliteus tendon and more medial meniscofemoral ligaments of Humphry and Wrisberg are often confused with vertical or peripheral meniscus tears.

Bucket handle, flap and displaced radial tears may appear as subtle alterations in signal intensity of the otherwise "black" meniscus. The hallmark of the meniscal lesion is intrameniscal signal alteration extending to an articular surface. Unfortunately this hallmark sign is often over emphasized at the expense of other important information. For example, failing to carefully inspect the size and configuration of the menisci and missing a displaced tear or a discoid meniscus (8).

Medial Collateral Ligament

These are best imaged on the axial and coronal T2 pulse sequences. MCL sprains usually involve the mid-proximal fibers. Less commonly proximal or distal avulsion occurs. Coronal T2 images will reveal meniscocapsular separation (as high signal fluid in the defect) associated with deep capsular fiber rupture. The axial plane will distinguish MCL versus medial retinacular tears.

Posterior Collateral Ligament and Lateral Collateral Ligament Injuries

These injuries are less common than MCL and ACL injuries. Both mid sub-

Fig 7. *Sagittal T2 fast-spin echo MR image demonstrates peripheral meniscal tear associated with small perimeniscal cyst.*

stance rents and distal avulsion events occur. Isolated LCL tears are uncommon -- there are usually other associated injuries (e.g., PCL, ACL, ITB, biceps femoris tendon, lateral joint capsule, popliteus tendon, or arcuate ligament) (9).

Mechanisms of injury for PCL and LCL injuries include: direct impact on the knee such as striking the dashboard at the moment of motor vehicle collision impact, a direct fall on the knee, as well as varus and rotary forces.

Popliteal Artery Dissection

Popliteal artery dissection occurs in 40% of knee dislocations. The imager should look for the footprints of dislocation which include cruciate, MCL, and LCL tears. At times an intraluminal popliteal thrombus or flap may appear on routine axial MRI images. MR angiography should also be considered.

Extensor Mechanism Overload

Patellar tendinosis, so called jumper's knee, results from repetitive strain/overload. Histologically this process involves mucoid degeneration and focal nodule formation. MRI will disclose deep superomedial fiber signal changes in fiber thickening adjacent the inferior patellar pole.

Iliotibial Band Friction Syndrome

This will appear as abnormal intramedullary MRI signal changes and ITB thickening as well as edema in the adjacent fat plane and lateral femoral condyle. When ITB friction syndrome is evident, look for an associated inflamed plica in the lateral knee synovial recess.

Fluid Enhanced Knee Joint Findings

These are changes which are easier to visualize when there is an effusion or upon instillation of intraarticular saline or gadolinium. Potential pathologies include patellar plica, synovitis and loose bodies. Gadolinium is necessary for visualizing recurrent meniscal tear versus granulation tissue, following an old meniscal tear or repair. T2 weighted fat suppression techniques may obviate the need for gadolinium in some instances.

The normal chondral anatomy (which includes three layers of different signal intensities) and the curvilinear knee joint surfaces necessitate imaging in all three planes. T2 weighted images with fat suppression is an accurate method of depicting chondral defects as it mitigates chemical shift artifact which may obscure some defects. Clinical scenarios which should raise the index of suspicion for chondral defects include: 1) In a setting of an ACL deficient knee; 2) In association with a meniscal tear; and 3) If the patient is status post meniscectomy.

Fig 8. *Coronal fat suppressed proton density fast-spin echo MR image demonstrates area of marrow edema indicating trabecular microfracture or bone bruise in the anterior aspect of the medial femoral condyle in a patient who had suffered a transient lateral patellar dislocation.*

Knee Bone Contusions and Fractures

These injuries are conspicuous on T1 weighted images or fat suppression (Fig. 8) and STIR pulse sequences. The imaging patterns of contusions provide insight into the mechanism of injury – therefore once identified inspect the knee for associated injuries. Possible associated injuries include transient patellar dislocation, ACL, PCL, MCL or LCL rupture.

Imaging of the Ankle and Foot

Although CT, scintigraphy and arthrography, as well as plain films, are still used to evaluate the foot and ankle, MR and MR arthrography are now recognized as premier imaging modalities in evaluating this anatomically and biomechanically complex region.

The sagittal, coronal, and transaxial (or plantar) are the cardinal MRI planes for the foot and ankle examination. Although the transaxial plane is often the most difficult to comprehend in terms of the anatomical relationships, it is often the most useful in garnering clinical information.

Both sagittal and transaxial planes allow adequate evaluation of the ankle and foot tendons while the coronal and transaxial planes are useful for assessing ankle ligaments.

Standard spin echo, gradient echo, and STIR pulse sequences are the techniques most commonly used. While fat suppression may have a role, it is difficult to achieve homogenous fat suppression over the entire image. Three-dimensional Fourier transform gradient recalled images yield rapid acquisition of contiguous foot and ankle sections, as well as reformations in oblique planes (parallel to the long axis of tendons). T1 weighted images allow for excellent anatomical delineation of the tendons while T2 weighted images disclose edema, fluid, hemorrhage or fibrosis about or in tendons and other soft tissue structures.

For hindfoot examinations the patient is placed in a supine position with slight flexion of the knee and ankle plantar flexion. Supine or prone positions may be used for mid and forefoot studies.

Capsular/synovial Abnormalities

Ankle effusions will manifest high signal on T2 weighted images. They can also be detected on lateral radiographs as a soft tissue density anterior and/or posterior to the joint. An ankle mortise effusion may communicate with the posterior subtalar joint. In the presence of any joint effusion other internal derangements must be suspected and systematically ruled out.

Adhesive capsulitis of the ankle is uncommon. Clinically it manifests as global restricted range of motion. The arthrographic hallmark of capsulitis in any joint is decreased joint capacity and irregular filling of the capsular recesses.

Ankle and foot synovial cysts usually extend in a posterior or posteromedial direction and may cause tarsal tunnel syndrome.

Connective tissue disorders commonly found in other joints may also be present in the foot and ankle. These entities include but are not limited to: gout (showing patchy low signal regions within the involved articulation on MRI), rheumatoid arthritis (which has a proclivity for the talonavicular joint with ligamentous hypertrophy and erosive joint changes), and pigmented villonodular synovitis (demonstrating low signal hemosiderin deposition within the synovial membrane which will demonstrate typical magnetic susceptibility distortion especially on gradient echo pulse sequences). As many tendon sheaths, particularly anteriorly, have an intimate relationship with the ankle joint, synovial pathology such as villonodular synovitis and tenosynovial osteochondromatosis may gain easy access to the ankle joint.

Bursal Disorders

Although there are several foot and ankle bursal cavities the retrocalcaneal bursa deserves special attention as it is commonly inflamed in patients with synovial and inflammatory diseases including rheumatoid arthritis. The retrocalcaneal bursa is identified as a small cap atop the calcaneus, between the Achilles tendon and the pre-Achilles fat pad. Only a tiny amount of fluid is usually present within the bursa unless it is inflamed. Haglund's syndrome is noted in patients with a prominent calcaneal tuberosity, retrocalcaneal bursitis, and often Achilles tendonitis as well as a more superficial bursitis.

Tendinous Foot and Ankle Pathology

Achilles Tendon

This structure upholds its mythological symbolism by being the longest and strongest tendon in the lower leg as well as one of the most commonly injured tendons in the foot (along with the tibialis posterior tendon). Look for abnormalities at the junction where the tendon changes from a cord-like configuration spiraling into a fan-like insertion on the calcaneal tubercle. The blood supply in this segment, which is 2-6 cm proximal from its calcaneal insertion, is tenuous.

Inflammatory conditions involving the Achilles tendon include tendonitis (intrasubstance inflammation), peritendinitis (inflammation surrounding the Achilles tendon) and peritendinitis (peritenon inflammation). These conditions all manifest as high T2 signal (1). Parenthetically, the Achilles tendon is absent a sheath. Chronic Achilles tendonitis can be seen as a diffusely or focally thickened tendon with or without accompanying peritendinitis. Along with focal or diffuse tendon enlargement discreet foci of increased T2 signal intensity suggest an accompanying small partial tear.

Complete Achilles tendon rupture is more common in men (5-6 times greater than women) and usually occurs in the 30-50 year age bracket. In an otherwise sedentary man with a history of pain upon sudden or forced dorsiflexion of the foot, look for a tendinous gap filled with blood and edema on T2 and STIR sequences.

Calcific tendonitis normally yields low signal on T1 and T2 pulse sequences (from calcium hydroxyapatite or calcium pyrophosphate dehydrate). Since tendons typically have low T1 and T2 signal, plain films and CT are better modalities to discern calcific tendonitis or intratendinous ossicles. Plain films most commonly reveal an enthesophyte at the calcaneal insertion. It is also possible to find a discreet ossicle within the tendon just proximal to its calcaneal insertion.

Diffuse thickening of the tendon or an intratendinous nodule may be seen in the urate tophi of gout, rheumatoid nodules and xanthomas in hypercholesterolemia.

Posterior Tibialis Tendinopathy

Again, pathology may be the result of a systemic articular disease (as a seronegative spondyloarthropathy) or result from abnormal foot and ankle mechanics.

Unlike the Achilles tendon ruptures, spontaneous posterior tibialis tendon rupture is more common in women in their 5th-6th decade of life. Ninety percent of the cases are unilateral.

Partial tears are divided into two types on both CT and MRI. Type I tears show hypertrophy and often longitudinal splitting. An abnormal increase in signal intensity is most readily seen in the enlarged or bifurcated tendon on proton density and occasionally on T2 weighted or STIR imaging. Type II partial tears results in attenuation, seen as diminished width. Complete tears present as a gap with or without tendon retraction.

Flexor Hallucis

Tendinopathy changes commonly occur at the level of the medial malleolus in athletes whose sport involves prolonged foot flexion such as dancers.

Anterior Tibialis Tendinopathy

Changes in this tendon are most often seen between the superior and inferior extensor retinacula. Spontaneous rupture of the anterior tibialis tendon is rare.

Abnormalities of the Peroneal Tendon

Subluxation or dislocation of the peroneal tendon may result from a single traumatic event or chronic overloading, leading to a functionally deficient retinaculum. Traumatic dislocations result from disruption of the superior retinaculum and/or stripping of the periosteum at the distal fibular retinacular attachment. On MRI look for fluid within the tear and adjacent boney attachment.

Altered biomechanics leading to edematous/thickened tendon, subluxation, dislocation or lateral calcaneal fracture may compromise the fibulocalcaneal space leading to an impingement syndrome or frank entrapment. Tendinitis and tenosynovitis can also be seen in connective tissue disorders, tarsal coalition, consequent to improper foot wear and congenital or acquired peroneal tubercle hypertrophy.

Ruptures of the peroneal tendon are most often the result of an acute injury such as a calcaneal fracture. When spontaneous ruptures do occur they most often involve the peroneus brevis tendon in young adults. Tendon rupture maybe accompanied by a fracture and tendon retraction (as far as the level of the lateral malleolus). Longitudinal splitting of the tendon may also occur.

Plantar Fascitis

Plantar fascitis may have a mechanical, degenerative or systemic etiology. MRI is the imaging modality of choice as scintigraphy changes are often non-specific. The fascia will appear thickened, up to 7-8 mm (from the usual 3-4 mm), and the signal intensity will be intermediate on T1 and high on T2 within the fascia, surrounding subcutaneous fat and at times the adjacent calcaneal marrow.

Plantar Fibromatosis

This condition is asymptomatic although plantar foot pain may become evident with prolonged walking or standing. Affected individuals have fibronodular proliferation and replacement of the plantar aponeurosis. This process shows characteristic nodules of low signal on T1, and either low signal intensity (with high collagen content) or high signal intensity (with increased cellularity) on T2 weighted scans.

Impingement Syndromes

Several impingement syndromes have been described including anterior impingement, posterior impingement, and anterolateral impingement. The anterior impingement syndrome involves degenerative osteophyte formation leading to impingement of the distal anterior tibia against the talar neck. In posterior impingement an os trigonum or prominent process on the posterior talar (i.e., Stieda's) restrict ankle motion. Anterolateral impingement results from a tear of the anterior talofibular ligament or other lateral ankle ligament causing intraarticular hemorrhage and synovial membrane hypertrophy. The latter extends into the lateral articular gutter of the ankle presenting normal motion. When evaluating a patient with a potential impingement syndrome plain films can depict boney changes such as degenerative osseous ridges accessory bones or osseous anomalies while MRI will best provide excellent delineation of ligamentous, synovial or other soft tissue involvement (1).

Ligamentous Abnormalities

The ankle ligaments are grouped in three complexes according to their location: 1) Tibiofibular; 2) Medial; and 3) Lateral.

The primary mechanism of injury for lateral complex disruption is inversion stress. Medial complex injuries are caused by eversion stress and often result in concomitant fibular fracture. Tibiofibular complex injuries also often result in fibular fractures but the mechanism of injury involves forced external rotation or dorsiflexion of the ankle.

These injuries should initially be evaluated with plain films including stress radiography (when undetected on static films) to appreciate instability and to detect fractures. MRI and arthrography can be used as complimentary modalities.

3DFT images are a powerful modality to evaluate ankle ligaments as they allow thin contiguous sections. As the ligaments are normally thin, have low signal intensity and are oriented in various planes, all three imaging planes must be acquired.

The anterior talofibular ligaments are readily identifiable on transaxial images as is the posterior talofibular ligament (although it is also visualized on the coronal scan). The latter is seen just anterior to the peroneus longus tendon and maybe mistaken for an intraarticular body as it appears as foci of low signal intensity at the posterior talus. Although it is imperceptible in 20% of normal ankles, the calcaneofibular ligament may be identified on either transaxial or coronal images. The peroneus tendon will be identified just superficial to the calcaneofibular ligament.

The entire deltoid ligament may be imaged in the coronal plane especially with the foot in 20 to 40 degrees of plantar flexion. To appreciate both the superficial and deep portions of the deltoid ligament, the transaxial images are also necessary. The anterior and posterior tibiofibular ligament exams require analysis of several consecutive transaxial images, particularly across the tibial plafond.

Ligament disruption on MRI presents as partial or full thickness interruption, ligament irregularity or thickening, waviness or laxity, and surrounding high signal fluid accumulation (including adjacent joints and tendon sheaths from hemorrhage and edema).

Sinus Tarsi Syndrome

This diagnosis should be suspected in patients presenting with an inversion injury, lateral ankle pain and a sense of weakness and instability. Unfortunately the MRI findings are non-specific consisting simply of poor definition of the soft tissue structures (specifically cervical and talocalcaneal interosseous ligaments as well as surrounding edema), and loss of the normal T1 hyperintense fat signal in the tarsal sinus.

Interdigital Neuromas

Morton's neuromas are most prevalent in young and middle aged females. Most commonly they are found in the interspace of the third and fourth toes. In contrast to true neuromas, which yield high T2 signal, interdigital neuromas have persistently low T1 and T2 signal intensities.

Osseous Abnormalities

Conventional arthrography and CT scanning have given way to MR arthrography for evaluating osteochondral fractures and osteochondritis desiccans so that not only the size of the lesion can be discerned but also any associated chondral defects, partially detached lesions and intraarticular bodies.

MRI imaging is particularly sensitive for detecting occult fractures (Fig. 9) and stress fractures (both of which are common in the ankle and foot). STIR and T1 weighted spin echo pulse sequences will indicate the presence of the fracture line as well as associated marrow edema.

Chronic overuse syndrome can be seen in adults as contusion of the distal tibia, fibula, and tarsal bones causing high signal on STIR and fat suppressed fast spin echo pulse sequences. It is also possible to see transient marrow edema syndrome involving the bones of the an-

Fig 9. *Sagittal T1 fast-spin echo MR image demonstrates a radiographically occult fracture of the distal talus.*

kle and foot, especially the talus. Typically the marrow edema will spontaneously resolve to reappear at a different site, for instance the knee.

There are many coalition anomalies. The talocalcaneal and calcaneonavicular are most prevalent. Talocalcaneal coalition is more accurately identified by CT or MRI while calcaneonavicular coalition can be easily detected on plain films. Coalitions may be acquired, secondary to septic or rheumatoid arthritis and seronegative spondyloarthropathy. As they alter the normal foot and ankle mechanics, they are a putative source of pain.

Spontaneous osteonecrosis of the navicular bone or Mueller-Weiss syndrome can be seen in adult patient's who are immunocompromised, diabetic or have renal disease and/or connective tissue disorders (i.e., SLE or RA).

Freiberg syndrome involves cortical thickening of the head of the second metatarsal bone, a shortened first metatarsal bone with associated joint effusion and intraarticular bodies in patients with forefoot pain. In this setting, it is important to exclude stress fractures of the adjacent metatarsal heads.

Summary

Understanding the indications for musculoskeletal imaging modalities and how alterations in imaging anatomy may reflect an injury mechanism provides the pain management physician a powerful compliment to their diagnostic armamentarium.

Author Affiliation:

Joseph D. Fortin, DO
Medical Director
Spine Technology and Rehabilitation
7230 Engle Road, Suite #210
Fort Wayne, IN 46804.
E-mail: fortin@pol.net

Edward C. Weber, DO
The Imaging Center
7631 W. Jefferson Blvd.
Fort Wayne, IN 46804
260-436-7770
E-mail: bigskyrad@mac.com

References

1. Resnick D. *Bone and Joint Imaging Second Edition*. WB Saunders Company, 1996.
2. Stoller DW. *Magnetic Resonance Imaging in Orthopaedics and Sports Medicine*. Lippincott Williams and Wilkins, 1997.
3. Rubin DA, Kneeland JB. MR imaging of the musculoskeletal system: Technical considerations for enhancing image quality and diagnostic yield. *AJR* 1994; 163:1155-1163.
4. Steinbach LS, Fleckenstein JL, Mink JH. Magnetic resonance imaging of muscle injuries. *Orthopedics* 1994; 17:991-999.
5. Conway WF, Totty WG, McEnery KW. CT and MR imaging of the hip. *Radiology* 1996; 198:297-307.
6. Vande Berg BE, Malghem JJ, Labaisse MA, et al. MR imaging of avascular necrosis and transient marrow edema of the femoral head. *Radiographics* 1993; 13:501-520.
7. Munk B, Madsen F, Lundorf E et al. Clinical magnetic resonance imaging and arthroscopic findings in knees: A comparative prospective study of meniscus, anterior cruciate ligament and cartilage lesions. *Arthroscopy* 1998; 14:171-175.
8. Roychowdhury S, Fitzgerald SW, Sonin AH et al. Using MR imaging to diagnose partial tears of the anterior cruciate ligament: value of axial images. *Am J Roentgenol* 1997; 168:1487-1491.
9. Ross G, Chapman AW, Newberg AR et al. Magnetic resonance imaging for evaluation of acute posterolateral complex injuries of the knee. *AM J Sports Med* 1997; 25:444-448.
10. Johnson DL, Urban W Jr., Caborn DN et al. Articular cartilage changes seen with magnetic resonance imaging-detected bone bruises associated with acute anterior cruciate ligament rupture. *Am J Sports Med* 1998; 26:409-414.
11. Harner CD, Hoher J. Evaluation and treatment of posterior cruciate ligament injuries. *Am J Sports Med* 1998; 26:471-482.
12. Nemeth WC, Sanders BL. The lateral synovial recess of the knee: Anatomy and role in chronic Iliotibial band friction syndrome. *Arthroscopy* 1996; 12:574-580.
13. Muellner T, Weinstabl R, Schabus R et al. The diagnosis of meniscal tears in athletes. *Am J Sports Med* 1997; 25:7-12.
14. Waldschmidt JG, Rilling RJ, Kajdacsy-Balla AA et al. In vitro and in vivo MR imaging of hyaline cartilage: Zonal anatomy, imaging pitfalls, and pathologic conditions. *Radiographics* 1997; 17:1387-1402.
15. Fritz RC, Brody GA. MR imaging of the wrist and elbow. *Clin Sports Med* 1995; 14: 315-352.
16. Oneson SR, Timins ME, Scales LM et al. MR imaging diagnosis of triangular fibrocartilage pathology with arthroscopic correlation. *AJR* 1997; 168:1513-1518.
17. Ho CP, Plancher KD, Fritz RC et al. Skier's thumb: MR imaging detections of the Stener lesion with surgical correlation in a double-blinded prospective study. *Radiology* 1995; 197:428.
18. Potter HG, Weiland AJ, Schatz JA et al. Posterolateral rotatory instability of the elbow: Usefulness of MR imaging in diagnosis. *Radiology* 1997; 204:185-189.
19. Cotten A, Jacobson J, Brossmann J et al. Collateral ligaments of the elbows: conventional MR imaging and MR arthrography with coronal oblique plane and elbow flexion. *Radiology* 1997; 204:806-812.
20. Timmerman LA, Schwartz ML, Andrews JR. Preoperative evaluation of the ulnar collateral ligament by magnetic resonance imaging and computed tomography arthrography: Evaluation in 25 baseball players with surgical confirmation. *Am J Sports Med* 1994; 22:26-32.
21. Gore RM, Rogers LF, Bowerman J et al. Osseous manifestations of elbow stress associated with sports activities. *AJR* 1980; 134:971-977.