MRI of the Knee: Update
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Introduction

Although the value of MRI in the evaluation of musculoskeletal conditions such as tumors, osteonecrosis, and inflammatory processes was apparent almost immediately after the introduction of this modality in the early 1980’s, early studies of knee imaging with MRI were inconclusive. Knee imaging was a more technically-demanding application of MRI, and the capabilities of the early low field systems were simply insufficient to adequately and reliably depict knee anatomy.

With the introduction of special closely coupled extremity RF coils, high field systems, and other technical advances, this situation changed dramatically. Knee imaging is now one of the most common non-neurological applications of MRI.

Role and Efficacy of Knee MRI

MRI has replaced arthrography in the evaluation of knee problems. Multiple studies have firmly established that meniscal tears can be detected with a sensitivity of 90-97%, and that the accuracy of MRI is equal to that of competently performed arthroscopy. Large studies have documented the value for routine MR imaging of the menisci prior to arthroscopic surgery. A significant fraction of patients with clinical evidence of meniscal tears are found not to have tears at arthroscopy (30% in one study). The high negative predictive value of MRI can spare many of these patients the costs and morbidity of arthroscopy.

While the efficacy of MRI for delineating meniscal pathology would alone provide the basis for its wide use in patients with knee dysfunction, the modality has also been established as useful for assessing other knee structures such as ligaments, cartilage, bones, and periarticular soft tissues.

Technique

Positioning

Like other MRI examinations, the protocol for knee imaging may be tailored to the individual patient. Typically, the patient is placed in a supine position, with the knee placed in a closely coupled extremity coil. In a comfortable neutral supine position, the knee is allowed to assume a slight (10-15 degree) externally-rotated position, in order to facilitate visualization of the anterior cruciate ligament in sagittal images.

Image Geometry

Multiplanar imaging is mandatory for most knee examinations. Sagittal, coronal and oblique sections are commonly employed, but transaxial images may be useful for assessing the patellofemoral compartment. No definitive guidelines have been established for the minimum spatial resolution required for knee MRI, but common sense suggests a minimum in-plane resolution of better than 1 mm and a section interval of 5 mm or less. Images obtained with 128 or fewer phase encoding views may contain misleading truncation artifacts. Placing the phase axis longitudinally in sagittal images (requires an anti-phase wrap feature) will prevent flow artifacts from popliteal vessels from degrading the depiction of cruciate ligaments in the midline.
Pulse Sequence

In choosing pulse sequences, the radiologist now has many options, ranging from spin echo sequences to various gradient echo sequences. The contrast requirements in knee imaging are mixed. Meniscal tears are best imaged with MR sequences that are neither purely T1 or T2 weighted. Other structures such as ligaments are best evaluated with T2-weighted images.

The pulse sequences that are now widely available for knee imaging are spin echo techniques and gradient echo techniques, both slice selective and 3DFT versions.

**Short TR Spin Echo**

Early publications on knee MRI found that meniscal pathology could be detected with T1-weighted spin echo images. However, subsequent experience and technical advances have yielded better techniques for most knee imaging tasks. At this time, there seems to be little to recommend the sole use of short TR/TE spin echo sequences for knee imaging. Although they are technically undemanding, rapidly acquired, and sensitive for medullary bone lesions, they only provide low contrast for meniscal lesions, they are not well suited for demonstrating acute ligamentous injuries or the interface between joint fluid and articular cartilage, and they require special windowing during photography.

**Long TR Spin Echo**

Long TR, multiecho spin echo sequences are very effective for knee imaging. A short first echo provides intermediate contrast which is excellent for identifying meniscal lesions and a second long echo provides T2-w contrast for evaluating the cruciate ligaments and other structures.

**Fast Spin Echo**

This sequence is a multishot version of the RARE technique. FSE sequences are well-suited for obtaining high resolution T2-weighted images. They are also highly resistant to susceptibility-induced signal losses and are therefore useful for depicting articular cartilage and tissue adjacent to metallic implants. Unfortunately, some FSE sequences are not very good at providing “proton-density” contrast, which is needed for evaluating meniscal tears.

**Gradient Echo**

Gradient echo techniques useful capabilities in terms of contrast and speed. These techniques can be broadly divided into “steady state” sequences such as GRASS and FISP, and “Spoiled” sequences such as FLASH and Spoiled GRASS.

Multislice gradient echo acquisitions can be performed in two ways: (1) Sequentially acquire each slice individually, or (2) Acquire the slices in an interleaved fashion similar to multislice spin echo imaging. In the specific application of knee imaging, the longer TR of the interleaved approach has the effect of improving the contrast and signal-to-noise characteristics of the images, compared with short TR gradient echoes.

These long TR, medium TE gradient echoes provide excellent contrast for delineating meniscal tears. An advantage of this technique is that special windowing of the images is not required. Long TR gradient echo sequences can provide very pronounced T2-weighted contrast for depicting ligamentous lesions. Long TR gradient echo images seem to have special capabilities for depicting chondral and osteochondral lesions.
**Meniscal Disease**

**Appearance**

The menisci are composed of fibrocartilage. This material tends to have a low signal intensity in many kinds of MR images, especially those that are T2- or T2*- weighted. Gradient echo images with moderate and short TE values will demonstrate areas of higher intrameniscal signal in normal children and young adolescents. Short TE gradient echo and spin echo images will also demonstrate mild diffusely increased signal intensity in older persons with varying degrees of meniscal degeneration. Gradient echo sequences with ultrashort TE values (6 ms or less) will demonstrate increased meniscal signal in most patients. Coronal, sagittal, and radial images demonstrate the menisci with a characteristic triangular shape.

**Meniscal Tears**

Arthroscopically-detectable meniscal tears are recognized in MR images as linear areas of increased signal intensity within the meniscal substance that extend to the articular surface. In the past, various grading systems were proposed for describing the patterns of increased signal intensity in menisci. Now that the significance of these patterns is understood, it seems appropriate to use more direct terminology in MRI reports. The intrameniscal signal associated with meniscal degeneration ranges in a spectrum from minimal central/peripheral changes, to marked diffuse intensity changes throughout a macerated meniscus. Discrete linear areas of high signal intensity that do not extend to the articular surface can indeed represent intrameniscal tears and may cause symptoms. The latter diagnosis should be made with caution, because arthroscopic confirmation is difficult, and the functional significance is uncertain.

While the majority of significant meniscal tears are easily delineated with MRI, it can occasionally be difficult to judge the significance of a small linear area of increased signal intensity. In this context, optimized examination protocols can yield better quality images that will prevent much hand wringing and philosophical debate about “grade 2 versus grade 3 signal”.

The most common sites for meniscal tears are the posterior horn of the medial meniscus and the anterior horn of the lateral meniscus. Morphologically, tears can be described as transverse, longitudinal and oblique. The most common transverse tear is the so-called “degenerative” tear of the posterior horn of the medial meniscus. These tears are very common in the elderly and may be mechanically stable and asymptomatic. Bucket-handle and flap tears are predominantly longitudinally oriented, as are radial and “parrot-beak” tears. Displaced bucket-handle and flap tears may be detected by noting the deficient size of the body of the meniscus, and by delineating the displaced fragment in sagittal, radial, and coronal images. Non-displaced peripheral meniscal tears (“meniscocapsular separation”) may be difficult to detect with MRI.
Pitfalls

Normal structures that anchor the menisci, such as the meniscofemoral and transverse ligaments can cause oblique areas of increased signal intensity where they fuse with the menisci. These should not be misinterpreted as tears. Partial volume effects can cause apparent linear areas of intrameniscal signal hyperintensity, but these are peripherally located and do not extend to the articular surface. The popliteus tendon bursa is closely situated to the periphery of the lateral meniscus and should not be mistaken for a peripheral tear of the meniscus.

If a low phase encoding resolution (128 views) is used for image acquisition, this may result in truncation or Gibbs artifacts which can cause linear areas of increased signal intensity to be superimposed on the menisci. This problem can be avoided by obtaining a higher number of views (such as 192). Similar linear artifacts can be caused by minimal patient motion during acquisition, such as tensing the quadriceps without moving the lower leg.

Discoid Menisci

Discoid menisci are not uncommon and can be clearly delineated with MRI. Discoid menisci should be carefully evaluated for tears or buckling.

Postoperative Menisci

The peripheral remnant of a partially resected meniscus can be readily defined with MRI, and new injuries can be detected. Unfortunately, the interpretation of residual intrameniscal signals extending to the neo-articular surface can be difficult, as these areas do not necessarily indicate a residual tear. Clear cut irregularity in the articular surface can and should be reported.

Ligaments

The major ligamentous structures that can be evaluated with MRI include the anterior and posterior cruciate ligaments and the medial and lateral collateral ligament complexes. The quadriceps tendon can also be clearly delineated with MRI. The role of MRI in evaluating ligaments is greatest in patients with acute injuries, where physical examination is difficult due to pain. Patients with chronic ligamentous injuries can usually be adequately evaluated for joint stability in the physical examination, and such findings will tend to take precedence over an imaging assessment of ligament integrity. Furthermore, the presence of fibrotic tissue in the course of a previously injured ligament may make evaluation by MRI difficult.

T2-weighted spin echo images provide suitable contrast for assessing ligaments, whereas they may be obscured in T1-weighted images by joint fluid, synovial hypertrophy, or edema in surrounding tissues.

Anterior Cruciate Ligament
This is the most frequently injured ligament of the knee. Careful technique is necessary in order to consistently visualize the anterior cruciate ligament (ACL). Sagittal images with intervals of 5 mm or less will reliably depict the length of the ligament if the knee is placed in slight external rotation. Over rotation or uncomfortable positioning will produce poor results.

The normal ACL appears smaller in diameter than the posterior cruciate ligament in T2-weighted images. The ligament also tends to have a slightly higher signal intensity than the PCL in short TE spin echo images, a phenomenon that has been variously attributed to partial volume effects, ligament structure, and “magic angle” effects. The ACL normally follows a smooth oblique or slightly curved path from its attachment on the medial side of the midline of the proximal anterior tibia, to the medial posterior aspect of the lateral femoral condyle.

In T2-weighted images, an acutely torn ACL will usually present with increased signal intensity interrupting the course of the ligament. Edema in the surrounding tissues presents a mass-like effect. In chronic tears, the inferior segment of the ACL may slump down to lie along the midline surface of the tibia.

A number of ancillary findings may be associated with ACL tears. After ACL interruption, the tibia may sublux anteriorly with respect to the femur. This may be observed in sagittal images by noting the position of the two bones, or indirectly by an alteration in the course of the PCL. The PCL normally has a smooth arched course from its posterior tibial attachment, anterosuperiorly to the posterolateral aspect of the medial femoral condyle. Anterior subluxation of the tibia with respect to the femur, permitted by interruption of the ACL, causes a buckled or “cobra head” appearance in the course of the PCL.

A very important association between a specific pattern of bone contusion and acute ACL tears has been described. The most common mechanism of injury for ACL tears can be characterized as an internal rotation of the tibia on the femur. This motion places stress along the axis of the ACL, and if completed, will result in a tear. During physical examination, interruption of the ACL may be detected by reproducing a portion of this motion in the moderately flexed knee; a finding called the “pivot shift” phenomenon. At the time of acute injury, the internal rotation of the tibia on the femur brings the anteroinferior aspect of the lateral femoral condyle into apposition with the posterior corner of the lateral tibia. The impaction of these two surfaces at the time of injury will often be cause localized bone contusions that can be easily identified in MR examinations. Patients with acute ACL tears have been found to have localized bone contusions in the posterolateral corner of the proximal tibia in almost 100% of cases. Contusions are present in the lateral femoral condyle in at least 50% of patients with ACL tears. Localized acute osteochondral injuries at this site are also common. In summary, after acute knee injury, the MRI finding of bone contusion in the posterolateral corner of the proximal tibia (with or without a contusion in the lateral femoral condyle) is almost invariably associated with an ACL tear.

### Posterior Cruciate Ligament

PCL tears are much less common than injuries of the ACL. T2-weighted images demonstrate such tears as localized areas of increased signal intensity, with or without surrounding edema depending on the acuteness of injury. In some examinations, the secondary results of PCL tear may be noted, with
posterior subluxation of the tibia with respect to the femur, and an abnormally longitudinal (rather than oblique) course of the ACL.

**Medial Collateral Ligament**

The medial (tibial) collateral ligament consists of a superficial layer that arises from the medial femoral epicondyle proximal to the knee joint and passes distally to attach to the tibia approximately 5 cm below the joint line. This layer is separated from a thinner deeper layer by a bursa which may become inflamed and symptomatic. The deep layer is attached to the periphery of the medial meniscus and to the femur and tibia adjacent to the joint line.

Tears of the medial collateral ligament are more common than those of the lateral ligament complex. They are associated with ACL tears in approximately one third of cases. Tears are best delineated in T2-weighted images, and surrounding soft tissue edema may be intense in acute injuries. Chronic tears may demonstrate fibrous thickening of the ligament complex. There appears to be poor correlation between the MR appearance of collateral ligament tears and the extent of biomechanical instability determined from adequate physical examination.

**Lateral Collateral Ligament**

The lateral ligament complex consists of the fibular collateral ligament (FCL), the iliotibial band, and capsular ligaments. The FCL is a cord-like structure extending from the lateral femoral epicondyle to the fibular head. It fuses with the tendon of the biceps femoris muscle to form the conjoint tendon. The FCL is not attached to the joint capsule and is usually separated from it by a thin layer of adipose tissue. It is less frequently torn than the MCL. Tears of the FCL are best delineated in T2-weighted images.

The iliotibial band is rarely torn, but may be subject to an overuse injury, especially in athletes, and manifested as increased signal intensity in tissues between the band and the adjacent lateral femoral condyle.

The lateral capsular ligament is fused to the capsule but not to the periphery of the lateral meniscus. The capsular ligaments are firmly attached to the femur and tibia adjacent to the joint line. An avulsion fracture of the lateral corner of the tibia resulting from traction of the capsular ligament is called a “Segond lesion”. ACL tears are almost always present in patients with Segond avulsion fractures, and meniscal tears are present in approximately one-half of such cases.

**Patellar and Quadriceps Tendons**

The quadriceps tendon has a layered appearance due to fusion of fascial layers of the four muscle groups forming it. The patellar tendon (sometimes called a “ligament”) passing from the patella to the anterior tibia has a more homogenous appearance except at the inferior margin of the patella, where there is a normal wedge-shaped area of increased signal intensity in the posterior portion of the tendon. Tears of the patellar and quadriceps tendons are easily delineated in T2-weighted images.
Degeneration of the patellar tendon may present as increased signal intensity in proton density (long TR/ short TE) images, and normal low signal intensity in T2-weighted images.

Patients with patellar instability may present with tears or insufficiency in the lateral and medial retinacula which fan medially and laterally from the patella, and which are best assessed in transverse T2-weighted images.

**Articular Cartilage**

Much knee symptomatology is attributable to disorders of articular cartilage. Unfortunately, the thin layer of hyaline cartilage covering the articular surfaces of the knee joint is much more technically difficult to image clearly than the menisci and ligaments. Various sequences have been advocated, including gradient echo and spin echo techniques. Accurate MRI assessment of articular cartilage is limited by magnetic susceptibility effects of adjacent bone cortex, by chemical shift misregistration, and by inherent limits in spatial resolution.

Careful scrutiny of MR examinations does reveal a substantial amount of information regarding articular cartilage. This includes an overall assessment of cartilage thickness and overall signal intensity. The presence, distribution, density, and depth of articular cartilage defects should be noted.

**Ischemic Bone and Osteochondral Disease**

This group of lesions includes osteochondritis dissecans, juxtaarticular osteonecrosis, and medullary infarcts. Osteochondritis dissecans is thought to represent avascular necrosis of juxtaarticular bone secondary to trauma. It most commonly occurs in the inferolateral aspect of the medial femoral condyle but may affect any part of the joint. It is readily identified with most pulse sequences, but T2-weighted and gradient echo images are best for assessing integrity of the overlying cartilage and stability of the bone fragment. Loose Intra-articular osteochondral fragments can be localized with MRI, but require careful and systematic image review for reliable detection.

Juxtaarticular osteonecrosis of the knee is most commonly seen in patients with a history of corticosteroid therapy, but the disease may also be idiopathic or secondary to a large list of other etiologies. Patients may present with symptoms suggesting internal derangement. The most common location for corticosteroid-induced or idiopathic AVN of the knee is the posterior aspects of the femoral condyles. The hallmark of uncomplicated AVN is the reactive interface, which is a thin layer of inflammatory tissue at the boundary of the infarct. This layer does not contain fatty marrow, and therefore it has low signal intensity in T1-weighted images and high intensity in T2-weighted images. The layer will enhance following administration of Gd-DTPA.

Medullary bone infarcts are typically seen in the elderly and in patients with collagen vascular disease or patients on corticosteroid medication. Deep medullary bone infarcts may be symptomatic but usually do not lead to complications such as fracture or collapse.

**Bone Injuries**

In the last several years, the powerful capacity of MRI to demonstrate bone injuries has become increasingly appreciated. The cortex of periarticular bone is much thinner than diaphyseal bone. In these regions, medullary bone plays a much more important role in the structural integrity of the skeleton than in diaphyseal areas. The spectrum of periarticular bone injury ranges from bone contusion to gross fracture. Bone contusion as an area decreased (T1-weighted images) or increased (T2-weighted images) signal intensity with ill defined margins. The overlying cortex may be intact. The etiology of bone contusion has been attributed to trabecular microfractures or shock wave phenomena. The edema associated with simple bone contusion will usually resolve over a period of
weeks following acute injury. Sometimes, a sclerotic healing reaction may produce areas of low signal intensity which may persist indefinitely. Bone contusions may be symptomatic.

Some periarticular traumatic bone lesions may have minimal plastic deformation of overlying cortex and articular cartilage in association with bone contusion. More significant injuries may be a discrete discontinuity in the cortex and overlying articular cartilage. The latter injuries may often be occult or missed on radiographic examinations.

The demonstration of bone injuries with MRI is significant from several aspects. (a) After trauma, the presence of bone contusions in a patient without coexisting MRI evidence of meniscal or ligamentous injuries can explain the presence of symptoms and may influence the program of rehabilitation. (b) A specific pattern of bone marrow edema may alert the radiologist to the presence of a ligamentous injury that otherwise would have been overlooked. (c) MRI may demonstrate clinically significant intra- and extra-articular fractures that are completely occult or difficult to detect radiographically.

**Plicae**

Plicae are folds of synovium that are thought to represent remnants of embryological divisions between knee compartments. The most important form of plica is a mediopatellar form that may project into the patellofemoral compartment from the medial aspect of the retropatellar bursa. If this fold of tissue becomes chronically irritated, possibly by being trapped between the articular surfaces of the patella and the femur, it may become thickened and symptomatic. The symptoms of plica syndrome may simulate those of a meniscal tear.

Mediopatellar plicae are often identified in patients with knee joint effusions. Most of these are incidental and asymptomatic. However, if the plica is thickened then the possibility of plica syndrome should be raised.
**Cysts and Effusions**

The most common cystic structure identified in knee MRI is the popliteal or Baker's cyst. This a bursal extension of the knee joint, usually located posterior to the medial aspect of the joint. There are many variations due to the large number of potential bursae arising from the posterior aspect of the knee. Popliteal cysts may have a septated appearance. Uncomplicated Baker’s cysts are easily differentiated from other types of masses in the popliteal region with MRI.

A variety of other bursal effusions may be present in the knee region. These include enlargement of the pes anserine bursa, which lies deep to the distal confluence of the tendons of the sartorius, gracilis, and semitendinosus muscles along the medial aspect of the proximal tibia. Bursal effusions arising from the proximal tibiofibular joint are not uncommon.

A normal cystic-appearing structure is the popliteus bursa, which is present along the posterolateral aspect of the lateral meniscus.

Meniscal and parameniscal cysts are much more common than suspected prior to the advent of MRI. They are invariably associated with a meniscal tear and may become so large that they may herniate posteriorly into the popliteal region. Diagnostic differentiation of meniscal and popliteal cysts is crucial because the surgical treatment is entirely different.

Knee joint effusions are common. With high field imagers, hemorrhagic effusions may occasionally be identified in patients with acute trauma due to the presence of hematocrit levels, or less commonly, low signal intensity throughout the joint fluid in T2-weighted images. MRI may also demonstrate fat-fluid levels in patients with intra-articular fractures.

**Arthritis and Synovial Disease**

MRI depicts changes in degenerative arthritis that mirror the findings in radiography. Patients with rheumatoid arthritis and other inflammatory arthritides may present with massive synovial thickening that can be difficult to differentiate from joint fluid even in T2-weighted images. Fat-suppressed T1-weighted imaging following administration of an intravenous Gd-Chelate has been found to provide exquisite delineation of the volume and extent of synovial hypertrophy.

Pigmented villonodular synovitis and synovial osteochondromatosis are two relatively rare diseases of synovium that have characteristic appearances in MR images.

**Periarticular Masses**

Unlike arthrography and arthroscopy, MRI depicts extracapsular as well as intracapsular structures. As such, radiologists interpreting knee MRI studies must be familiar with the range of abnormalities and mass lesions that can present incidentally or masquerading as knee lesions such as popliteal cysts. The range of such lesions includes hematomas, bone tumors, soft tissue sarcomas, lipomas, neural tumors, muscle tears, aneurysms of the popliteal artery, and deep venous thrombosis.