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Journal
Skeletal Radiology, 19(6)

ISSN
0364-2348

Authors
Bassett, Lawrence W
Grover, Jaswinder S
Seeger, Leanne L

Publication Date
1990-08-01

DOI
10.1007/bf00241788

Skeletal Radiol (1990) 19:401–405

Skeletal
Radiology

Magnetic resonance imaging of knee trauma

Lawrence W. Bassett, M.D., Jaswinder S. Grover, M.D., and Leanne L. Seeger M.D.

Department of Radiological Sciences, UCLA School of Medicine, Los Angeles, California, USA

Abstract. This article reviews the magnetic resonance (MR) appearance of normal knee anatomy and the role of MRI in the evaluation of knee trauma. Images acquired in the sagittal plane are the most useful. A combination of T_1- and T_2-weighted spin echo pulse sequences is most commonly employed. A meniscal tear is identified by an intrameniscal signal which extends to the joint surface. MR and arthroscopic findings agree in more than 90% of patients. It is important to be familiar with the MRI appearance of normal anatomic variants that may be confused with meniscal tears: the transverse geniculate ligament, the hiatus of the popliteal tendon sheath, and the meniscofemoral ligaments. Tears in the anterior cruciate, posterior cruciate, and collateral ligaments are also depicted.

Key words: Magnetic resonance imaging (MRI) – Knee, imaging – Knee, meniscus injury – Knee, ligament injuries

Magnetic resonance (MR) imaging is rapidly becoming the examination of choice for a variety of disorders of the knee. The use of a surface coil and thin-section, high-resolution scanning techniques in multiple planes has enhanced the depiction of structural details [11, 12, 13, 15, 19]. The inherent high soft tissue contrast of MRI differentiates structures such as fat, bone marrow, muscle, hyaline cartilage, joint fluid, menisci, and tendons (Table 1). MRI is rapidly replacing arthrography in evaluating internal derangements of the knee and may obviate, or complement, diagnostic arthroscopy. This article reviews the MR examination of the knee, the appearance of the normal anatomy and the evaluation of trauma.

Evaluation of trauma

The imaging planes and technical parameters used to acquire MR images depend on the type of system and the clinical problem [15]. It is important to develop an understanding of the kind of information that will be most useful to referring clinicians. The sagittal plane is generally the most effective for revealing internal derangements of the knee. Coronal imaging is needed for evaluation of medial and lateral collateral ligament complexes, and axial imaging depicts the patellofemoral joint best.

Meniscal tears

In imaging the meniscus, the overall agreement between MR and arthroscopic findings has been reported to be 93%, with a negative predictive value of 94% (the percentage of patients with a negative MR examination who do not have a tear at arthroscopy) [14].

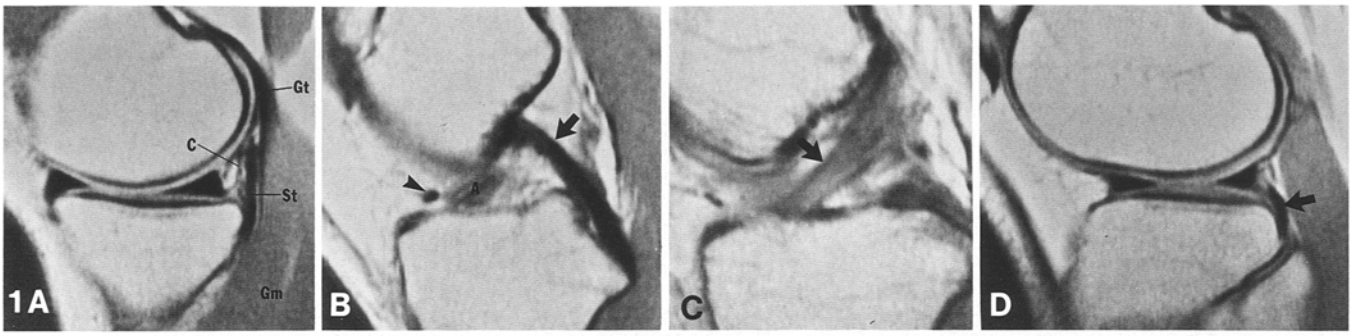
The normal meniscus is homogeneously black (devoid of signal) (Fig. 1). A meniscal tear is identified on MR images by the presence of an intrameniscal signal that extents to the meniscal surface (Fig. 2). A globular or linear focus of signal in the meniscus that does not extend to the joint surface will not represent a tear at arthroscopy (Fig. 3).

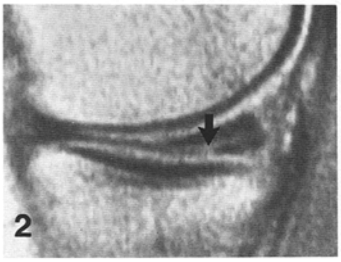
Table 1. Signal characteristics for T_1- and T_2-weighted magnetic resonance images

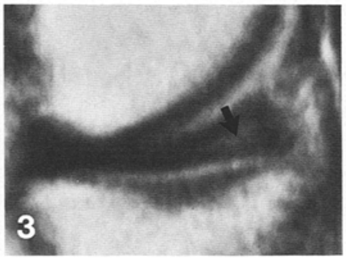
Tissue	T_1	T_2
Cortical bone	Void	Void
Ligaments, tendons	Void	Void
Fibrocartilage	Void	Void
Normal fluid	Low	High
Tumor	Low	High
Abnormal fluid	Intermediate	High
Hyaline cartilage	Intermediate	Intermediate to high
Muscle	Intermediate	Intermediate
Fat (marrow)	High	Intermediate to high

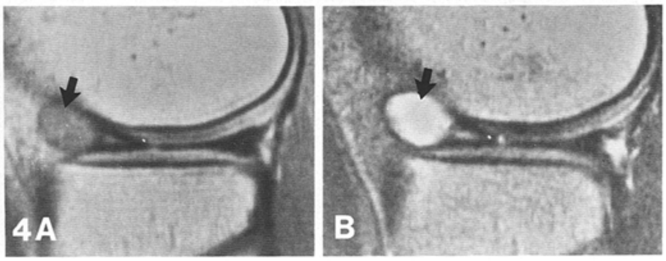
The following article is one in a series of review articles which represent expansions of papers presented at the annual meeting of the International Skeletal Society and were solicited by the editors

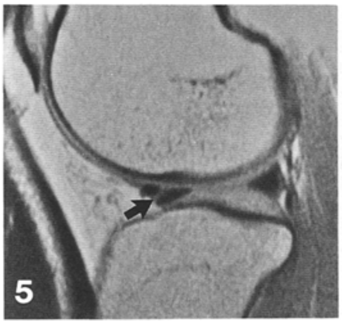
Address reprint requests to: L.W. Bassett, M.D., Department of Radiological Sciences, UCLA School of Medicine, Los Angeles, CA 90024, USA











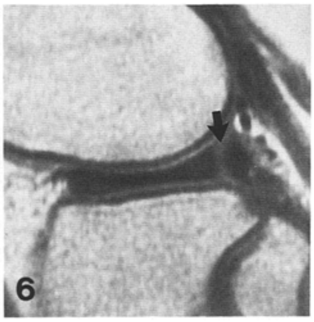


Fig. 1 A–D. Normal sagittal T_1-weighted images (SE 800/30), medial to lateral. **A** Medial aspect of the knee. The normal fibrocartilaginous medial meniscus, tendons of M. semimembranosus (*St*) and medial head of M. gastrocnemius (*Gt*), joint capsule (*C*), and cortical bone are devoid of signal. M. gastrocnemius (*Gm*) has an intermediate signal intensity. Fat, bone marrow, and hyaline cartilage have high signal intensity. **B** The low signal intensity posterior cruciate ligament (*arrow*) is an arcuate structure extending from the posterior tibial plateau to the medial aspect of the intercondylar notch. Just anterior to the origin of the anterior cruciate ligament (*A*), the transverse geniculate ligament (*arrowhead*) is seen passing between the anterior horns of the medial and lateral menisci. **C** The intermediate signal intensity anterior cruciate ligament (*arrow*) extends from the anterior tibial plateau to the intercondylar notch. **D** Lateral aspect of the knee. The popliteal tendon (*arrow*) is a low signal intensity structure within the popliteal sheath. It passes adjacent to the posterior horn of the lateral meniscus

Fig. 2. Sagittal T_1-weighted image (SE 800/30). Arthroscopically confirmed meniscal tear (*arrow*) has a high signal intensity and communicates with the surface of the meniscus

Fig. 3. Sagittal T_1-weighted image (SE 800/30). Focus of high signal intensity (*arrow*) within the meniscus does not extend to the meniscal surface. A tear was not present at arthroscopy

Fig. 4 A, B. Meniscal cyst. **A** T_1 (SE 800/30)- and **B** T_2 (SE 2000/85)-weighted images show the fluid-filled cyst (*arrow*) communicating with a tear in the meniscus

Fig. 5. Space (*arrow*) between the low signal intensity transverse geniculate ligament and low signal intensity anterior horn of the medial meniscus may mimic a meniscal tear

Fig. 6. Sagittal image (SE 800/30). Space (*arrow*) between the popliteal tendon and the posteror horn of the lateral meniscus may simulate a meniscal tear

A chronic meniscal tear may communicate with a fluid-filled cyst (meniscal cyst; Fig. 4) [3]. These cysts at the meniscocapsular margin are believed to result from the extravasation of fluid from the joint through the meniscal tear. They may occasionally extend beyond the confines of the joint, especially when they are located at the posteromedial aspect.

Pitfalls in the evaluation of meniscal tears

Several normal anatomic structures or normal variants may be confused with meniscal abnormalities. These include the transverse geniculate ligament, the hiatus of the popliteal tendon sheath at the lateral meniscus, and the anterior and posterior meniscofemoral ligaments.

The transverse geniculate ligament, or transverse meniscal ligament, is a band that connects the anterior horns of the medial and lateral menisci (Fig. 1 B). When this ligament is present, its thickness varies [17]. The space between the medial meniscus and the transverse ligament can mimic an anterior horn meniscal tear (Fig. 5) [10].

The popliteal tendon forms one of the lateral restraints of the knee. It passes from its origin on the lateral femoral epicondyle through the posterior fossa of the knee to its muscular insertion on the posterior surface of the proximal tibia [17]. The space separating the popliteal tendon from the adjacent posterior horn of the lateral meniscus may be mistaken for a tear of the posterior horn of the lateral meniscus (Fig. 6) [10].

The meniscofemoral ligaments are accessory structures that extend from the posterior horn of the lateral meniscus to the lateral aspect of the medial femoral condyle. The anterior ligament of Humphry passes in front of the posterior cruciate ligament (Fig. 7), and the posterior ligament of Wrisberg passes behind it [21]. These ligaments are believed to play a role in bringing the lateral meniscus forward when the knee is flexed, thus protecting the meniscus from being impacted between the femoral and tibial condyles [9]. Cadaveric studies have shown that the size and presence of these ligaments are variable. A meniscofemoral ligament, either the anterior ligament of Humphry or the posterior ligament of Wrisberg, is present in 58.5% of patients [8]. On sagittal images, the meniscofemoral ligaments may be mistaken for post-traumatic intra-articular fragments in the region of the posterior cruciate ligament, or the gap between the posterior meniscofemoral ligament and the posterior horn of the lateral meniscus may simulate a meniscal tear (Fig. 8).

Cruciate ligaments

Anterior cruciate ligament. A tear of the anterior cruciate ligament is one of the most common injuries to the knee [22]. The usual mechanism of injury is forced internal tibial rotation of a flexed knee. Another mechanism is external tibial rotation with a valgus force which may produce O'Donoghue's triad: the combination of anterior cruciate, medial meniscal, and medial collateral ligament tears. Clinical tests for anterior cruciate ligament deficiency include the anterior drawer test and the Lachman test. The anterior drawer test involves anterior displacement of the tibia by the examiner's hands, which are placed behind the proximal tibia with the knee in 90° of flexion. The Lachman test is similar, placing the knee in external rotation and 30° of flexion which may release secondary restraint [5]. These tests have been reported to have a sensitivity and specificity of 78% and 89%, respectively [12]. The sensitivity of MRI has been reported to be 92%–100%, its specificity 95%–96.9%, and its overall accuracy 95%–97.3% [14, 18].

The anterior cruciate ligament originates from the tibial plateau anterior to the tibial spine. It inserts on the posterolateral wall of the femoral intercondylar notch and the posterior aspect of the lateral femoral condyle. This structure is optimally visualized in sagittal images performed with the knee externally rotated 15°–20°. The normal anterior cruciate ligament is straight and fan-shaped (wider at its femoral attachment) (Fig. 1B). Unlike other ligaments around the knee, which are devoid of signal, it normally has a low to intermediate signal intensity.

A torn anterior cruciate ligament may be demonstrated on MR images by the absence or abnormal course of the ligament or by high signal intensity fluid traversing the ligament on a T_2-weighted sequence (Fig. 9). The most common site of a tear is near the femoral attachment [14].

Posterior cruciate ligament. There has been an increasing awareness of the clinical importance of early detection and treatment of posterior cruciate ligament injuries [2]. These injuries cause posterior instability of the knee, which is manifested as discomfort and a feeling of unsteadiness and insecurity when the knee is in the semiflexed position, as when descending stairs [4].

Posterior cruciate ligament injuries may elude clinical detection. Physical examination frequently yields equivocal results, and associated injuries may mask a tear. Arthrographic assessment is also of limited value [16]. MRI appears to be the most sensitive means of detecting posterior cruciate ligament injuries [8].

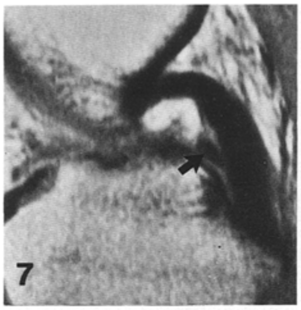
The posterior cruciate ligament originates from the tibial plateau posterior to the spine and inserts on the anterior aspect of the medial wall of the intercondylar notch. Normally it has a very low signal intensity and is arcuate in shape when the knee is in extension or mild flexion (Fig. 1B). It becomes increasingly taut as the knee is flexed [8], making the ligament more vulnerable to trauma.

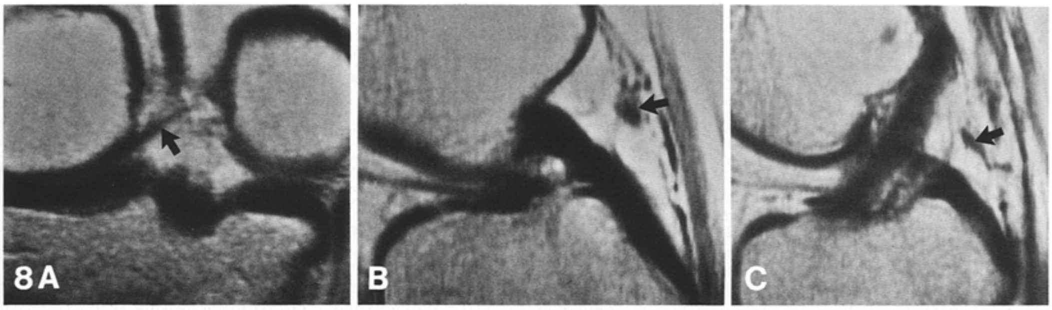
Tears of the posterior cruciate ligament are identified in sagittal T_1-weighted images by disruption of the ligament and are more obvious on T_2-weighted images due to the high signal intensity of fluid within the tear (Fig. 10) [8]. Avulsion of the ligament from its tibial attachment is identified on MR images by bony fracture of the posterior tibial plateau and redundancy of the ligament.

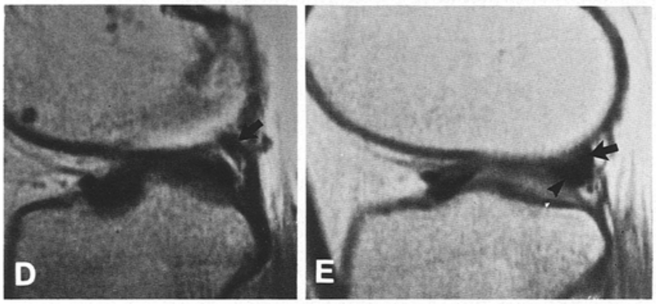
Collateral ligament complexes

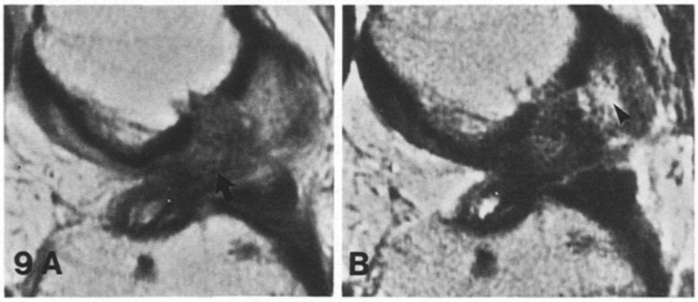
The structures that provide medial stability to the knee include the medial collateral ligament, the phylogenetic analogue of the tendon of the adductor magnus, and the deep capsular ligament, which represents a thickening of the medial joint capsule and is closely apposed to the medial meniscus [22]. A bursa with signal intensity of fat separates the medial collateral ligament from the capsular ligament. The medial collateral ligament complex is most commonly injured by a valgus stress due to a direct blow to the lateral aspect of the knee [1].

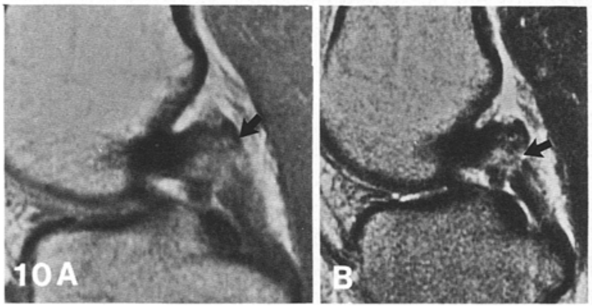
The structures that provide lateral stability can be divided into anterior, middle, and posterior thirds [7]. The anterior structures are actually more important for patellofemoral stability. These include the capsule, extending from the patellar tendon to the iliotibial band, and the lateral expansion of the quadriceps tendon. The middle third provides major lateral static support. It consists of the iliotibial band and the deep capsular ligament which extend posteriorly to the anterior border of the fibular collateral ligament. The posterior third, collectively referred to as the arcuate ligament complex, includes the fibular collateral ligament, the arcuate ligament, the tendoaponeurotic portion of M. popliteus, and the tendon of M. biceps femoris. Injuries to the lateral

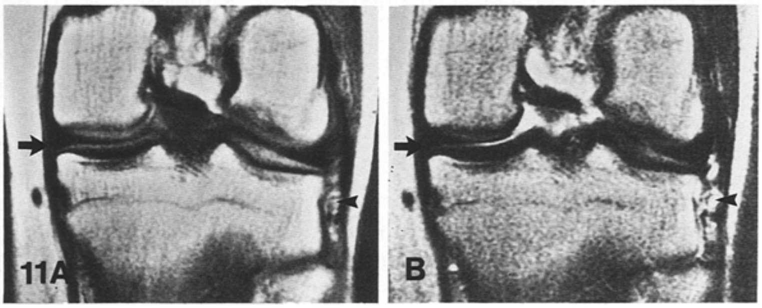












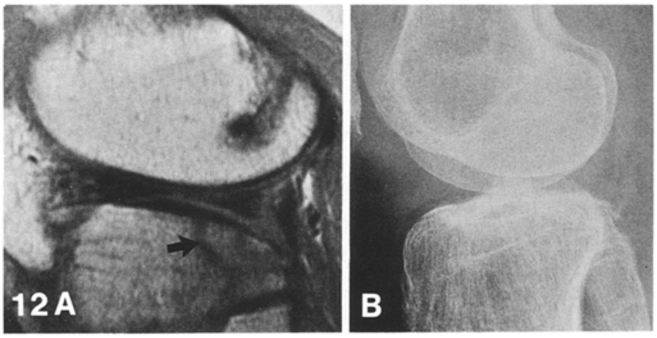


Fig. 7. Sagittal image (SE 800/30). Anterior meniscofemoral ligament (*arrow*)

Fig. 8A–E. Posterior meniscofemoral ligament. Coronal T_1-weighted image (SE 800/30) (**A**) shows the ligament (*arrow*) adjacent to the posterior horn of the lateral meniscus. Sagittal T_1-weighted images (SE 800/30), medial to lateral, depict the ligament (*arrow*) coursing from behind the posterior cruciate ligament (**B**) and the anterior cruciate ligament **C** to the posterior horn of the lateral meniscus (*arrowhead*) (**C**, **D**). The space between the ligament and the meniscus can simulate a meniscal tear (**E**)

Fig. 9A, B. Torn anterior cruciate liagment. The ligament (*arrow*) is grossly distorted on the T_1-weighted image (SE 800/30) (**A**), and there is high signal intensity fluid (*arrowhead*) within the tear on the T_2-weighted image (**B**)

Fig. 10A, B. Torn posterior cruciate ligament. The ligament (*arrow*) is grossly distorted on the T_1-weighted image (SE 800/30) (**A**), and there is high signal intensity fluid (*arrow*) within the tear on the T_2-weighted image (SE 2000/85) (**B**)

Fig. 11A, B. Collateral ligaments. **A** Coronal T_1 (SE 800/30)- and **B** T_2 (SE 2000/85)-weighted images show a normal medial collateral ligament complex (*arrow*). The lateral ligament complex presents an abnormally high signal intensity (*arrowhead*)

Fig. 12A, B. Fracture. Sagittal T_1-weighted image (SE 2000/85) at lateral aspect of the knee (**A**) shows nondisplaced fracture of tibial plateau (*arrow*), which was not identified on original radiograph (**B**)

ligaments of the knee are less frequent than injuries to the anterior cruciate or medial collateral ligaments. Isolated injuries of the lateral ligaments are rare.

Collateral ligament injuries are graded clinically according to the following classification: Grade I is a sprain or stretching of the ligament with localized tenderness but no clinical instability; grade II is partial disruption of the fibers with localized tenderness and mild to moderate laxity and a firm endpoint; grade III is a complete disruption of the ligament with significant instability and indistinct endpoint to laxity on valgus stress [24].

Normal medial and lateral ligament complexes are visualized as low signal intensity bands on both T_1- and T_2-weighted images. Injuries are identified by an increased signal intensity due to edema and hemorrhage, increased thickness, abnormal configuration, and/or discontinuity of the ligament [6, 20, 22] (Fig. 11).

Other injuries

Its high soft tissue contrast and multiplanar imaging capabilities make MRI an excellent means of evaluating other ligaments and tendons around the knee. MRI may be useful in determining the integrity of the patellar ligament when clinical examination is equivocal and in identifying the exact location of the injury. Localized accumulations of fluid or blood within a bursa can also be identified.

On T_1-weighted images, a fracture will be identified as a linear low signal intensity line extending to the cortex (Fig. 12). There may be an associated high signal intensity on T_2-weighted images. Sometimes fractures evident on MR images cannot be seen on radiographs, even in retrospect. Localized subchondral abnormal bone marrow signal intensity may also be seen after trauma. It has been suggested that these regions may represent trabecular fractures [23].

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