Imaging of the Knee

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Introduction

This article addresses the spectrum of imaging modalities that are commonly used in the knee, and describes their roles in the evaluation of particular knee disorders. Emphasis is placed on magnetic resonance imaging (MRI) and its value in knee trauma and on the biomechanical approach to understanding patterns of injury.

Imaging Modalities

Conventional radiographs are the initial radiologic study in most suspected knee disorders. Radiographs demonstrate joint spaces and bones, but are relatively insensitive to soft-tissue conditions (except those composed largely of calcium or fat), destruction of medullary bone, and early loss of cartilage. A minimum examination consists of an AP and lateral projection. In patients with acute trauma, performing the lateral examination cross-table allows identification of a lipohemarthrosis, an important clue to the presence of an intraarticular fracture [1]. The addition of oblique projections increases the sensitivity of the examination for nondisplaced fractures, especially those of the tibial plateau [2]. For the early detection of articular cartilage loss, a PA radiograph of both knees with the patient standing and knees mildly flexed is a useful adjunct projection. A joint space difference of 2 mm side-to-side correlates with grade III and higher chondrosis [3]. The tunnel projection is useful to demonstrate intercondylar osteophytes. In patients with anterior knee symptoms, an axial projection of the patellofemoral joint, such as a Merchant view, can evaluate the patellofemoral joint space and alignment [4].

Bone scintigraphy with an agent such as Tc99m-MDP can screen the entire skeleton for metastatic disease. Scintigraphy also has a role in the detection of other radiographically occult conditions, such as nondisplaced fractures, and early stress fractures, osteomyelitis, and avascular necrosis, especially with three-phase technique. Bone scanning is a useful adjunct in the evaluation of painful knee arthroplasties [5]. Evaluation of a potentially infected arthroplasty usually requires combining the bone scan with an additional scintigraphic examination, such as a sulfur colloid, labeled white blood cell, or inflammatory agent scan [6].

Sonography is largely limited to an evaluation of the extraarticular soft tissues of the knee but, with careful technique, at least partial visualization of the synovium and ligaments is also possible [7]. Ultrasound is useful in the evaluation of overuse conditions of the patellar tendon [8]. Also, sonography easily demonstrates popliteal (Baker’s) cysts [9].

Computed tomography (CT) is used most frequently to evaluate intraarticular fractures about the knee, for planning complex orthopedic procedures, and for post-operative evaluation. Maximal diagnostic information may necessitate reformattting the transversely acquired dataset into orthogonal planes and/or 3D projections [10]. To facilitate reconstructions, multidetector-row helical acquisitions with thin collimation (sub-millimeter, if possible) are preferred [11]. Combining helical CT with arthrography makes it a viable examination for the detection of internal derangements, including meniscal and articular cartilage injuries [12, 13].

Magnetic resonance imaging has emerged as the premier imaging modality for the knee. It is the most sensitive, noninvasive test for the diagnosis of virtually all bone and soft-tissue disorders in and around the knee. Additionally, MRI provides information that can be used to grade pathology, guide therapy, prognosticate conditions, and evaluate treatment for a wide variety of orthopedic conditions in the knee. MR arthrography following the direct intraarticular injection of gadolinium-based contrast agents increases the value of the examination in selected knee conditions, including evaluation of the post-operative knee, detection and staging of chondral and osteochondral infractions, and discovery of intraarticular loose bodies [14, 15, 16].

High-quality knee MRI can be performed on high- or low-field systems with open, closed, or dedicated-extremity designs, as long as careful technique is used [17, 18]. Use of a local coil is mandatory to maximize signal-to-noise ratio [19]. Images are acquired in transverse, coro-
nal, and sagittal planes, often with mild obliquity on the sagittal and coronal images to optimize visualization of specific ligaments [20, 21]. A combination of different pulse sequences provides tissue contrast. Spin-echo T1-weighted images demonstrate hemorrhage, as well as abnormalities of bone marrow, and extraarticular structures that are bounded by fat [22, 23]. Proton-density-weighted (long repetition time, short effective echo time) sequences are best for imaging fibrocartilage structures like the menisci [24]. T2- or T2*-weighted images are used to evaluate the muscles, tendons, ligaments, and articular cartilage [25, 26]. These fluid-sensitive sequences can be obtained using spin-echo, fast spin-echo, or gradient-recalled techniques. Suppressing the signal from fat increases the sensitivity for detecting marrow and soft-tissue edema [27, 28].

3D gradient-recalled acquisitions can provide thin contiguous slices for supplemental imaging of articular cartilage [29, 30]. To consistently visualize the critical structures in the knee, standard MRI should be done with a field-of-view no greater than 16 cm, 3- or 4-mm slice thickness, and imaging matrices of at least 192×256. Depending on the MR system and coil design, in order to achieve this spatial resolution with adequate signal-to-noise, other parameters, like the number of signals averaged and the receive bandwidth, may need to be optimized [31, 32].

Specific Disorders

Bone and Articular Cartilage

Osseous pathology in the knee encompasses a spectrum of traumatic, reactive, ischemic, infectious, and neoplastic conditions. Radiographs, CT, scintigraphy, and MRI each have a role imaging these disorders.

Trauma

Most fractures are visible radiographically. A lipohe-marthrosis indicates an intraarticular fracture, which may be radiographically occult, if it is nondisplaced [33]. The amount of depression and the congruence of the articular surface(s) determine the treatment and prognosis of tibial plateau fractures. The images need to accurately depict the amount of depression, as well as the presence, location, and size of any areas of articular surface step-off, gap, or die-punch depression. CT is better than radiography for this indication, with the use of multiplanar sagittal and coronal reconstructed images [34]. At some institutions, MR has supplanted CT. The MR examination not only shows the number and position of fracture planes, but also demonstrates associated soft-tissue lesions – such as meniscus and ligament tears – that may affect surgical planning [35].

Other common fractures about the knee include patellar fractures, intercondylar eminence fractures, and avulsions. Patellar fractures with a horizontal component require internal fixation when they become distracted due to retraction of the proximal fragment by the pull of the quadriceps. Fractures of the intercondylar eminence and spines of the tibia may affect the attachment points of the cruciate ligaments. Elevation of a fracture fragment may occur due to the attachment of one of the cruciate ligaments. Avulsion fractures may look innocuous, but they can signal serious ligament disruptions. For example, a fracture of the lateral tibial rim (Segond fracture) is a strong predictor of anterior cruciate ligament disruption, while an avulsion of the medial head of the fibula (arcuate fracture) indicates disruption of at least a portion of the posterolateral corner [36, 37].

Bone scintigraphy, CT, or MRI are more sensitive than radiographs for nondisplaced fractures. A positive bone scan after trauma indicates a fracture, as long as there are no other reasons (osteoarthritis, Paget disease, etc.) evident radiographically. However, an abnormal bone scan still does not show the number and position of fracture lines, which impacts treatment. For this reason, and because of the low specificity of bone scintigraphy, CT and MRI have largely replaced it for this indication. MRI probably has an advantage over CT: when there is no fracture present, MRI can show soft-tissue injuries that may clinically mimic an occult fracture. On MRI examination, non-fat-suppressed T1-weighted images best demonstrate fractures, where they appear as very-low-signal intensity linear or stellate lines surrounded by marrow edema, which has lower signal intensity than marrow fat, but is approximately isointense compared to muscle. On gradient-recalled, proton-density-weighted, and non-fat-suppressed T2-weighted images, fractures lines and marrow edema are often not visible. Marrow edema is most conspicuous on fat-suppressed T2-weighted or short-inversion time recovery (STIR) images, but the amount of edema may obscure underlying fracture lines.

Injuries to the articular surfaces often produce changes in the underlying subcortical bone. In children, these injuries are usually osteochondral, while in adults they may be purely chondral. The osteochondral fractures are visible radiographically, most often involving the lateral aspect of the medial femoral condyle. MRI is the study of choice to stage these lesions. On T2-weighted images, a thin line of fluid-intensity signal surrounding the base of the lesion indicates that the fragment is unstable. Similarly, the presence of small cysts in the base of the crater, or of an empty crater, indicates lesion instability, usually necessitating operative fixation or removal of the osteochondral fragment [38]. Lack of any high signal at the junction between a fragment and its parent bone indicates that the lesion has healed. The most difficult cases are those in which there is a broad area of high signal intensity that is less intense than fluid at the interface. In these instances, the high signal intensity may represent loose connective tissue of an unstable lesion or granulation tissue in a healing lesion. MR arthrography following the direct injection of gadolinium is helpful in this event: Gadolinium tracking around the base of the lesion indicates a loose, in-situ fragment [39].