Update on MR Imaging of the Knee

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Overview

In this section we will discuss the utility of the traditional classification system for Magnetic Resonance (MR) imaging of medial collateral ligament (MCL) tears, revisit the imaging and treatment of posterior cruciate ligament (PCL) injuries, and investigate the use of MR imaging for detecting particle disease after total knee arthroplasty.

Imaging of MCL Tears

The traditional MR imaging classification system for MCL injuries is characterized by three different grade levels. In a grade one (or a first degree injury) the fibers of the MCL are stretched but remain intact. In a grade two (or second degree injury) the fibers of the MCL are partially disrupted and there is increased laxity of the MCL. In grade two injuries there is a loss of resistance to valgus strain but a definite endpoint is detectable. A grade three (or third degree) injury of the MCL is characterized by complete disruption of the ligament and marked laxity on physical exam. There is little resistance to valgus stress and no endpoint is noted on physical examination.

The traditional classification system for MCL ligament injury has utility in separating low grade from high grade injuries (i.e. complete vs. incomplete injuries) but tends to overestimate low grade injuries. Fluid in or around the MCL is indicative of low grade MCL injuries but can also be seen with a number of other entities including osteoarthritis, chondromalacia, meniscal tears, meniscal extrusion, parameniscal cysts and MCL bursitis[1, 2]. One must look for these other entities before attributing the fluid to an MCL injury as fluid in this region will most often not be indicative of an MCL injury. The clinical history is also of paramount importance as valgus stress injuries are integrally related to MCL injuries.

The traditional grading system also focuses strictly on the MCL itself (figure 1). The medial and posteromedial knee has anatomic relationships that are more complex than a simple band like MCL. These anatomic relationships contribute to the integrity of the medial and posteromedial knee and injuries to the MCL most often involve not only the MCL but many of the surrounding structures. An accurate description of the injured structures is necessary to precisely characterize the injury and to determine what treatment would be optimal to remedy the underlying abnormality

The MCL has both anterior and posterior components and is the primary medial stabilizer of the knee joint. The anterior component is the MCL proper and the posterior component is designated the posterior oblique ligament (POL). The anterior component has both superficial and deep layers and, along with the POL, is involved in maintaining dynamic and static stability of the medial portion of the knee. The MCL attaches to the vastus medialis obliquus (VMO) fascia and medial retinaculum anteriorly, is continuous with the posterior knee joint capsule and semimembranosis and the deep fibers connect to the meniscus posteriorly. The POL extends from the VMO tubercle to the tibia and the posterior aspect of the knee joint capsule. The POL has an inferior arm that attaches to the semimembranosis tendon sheath and a superior arm that is continuous with the posterior capsule of the oblique popliteal ligament.

Isolated tears of the MCL are unusual and the vast majority of ligamentous injuries occur in concert with injuries to other medial and posteromedial structures. Some of the most common injuries that may occur in combination with MCL tears are tears of the anterior cruciate ligament (ACL), meniscal tears, meniscocapsular separations, injuries to the medial patellofemoral ligament (MPFL) or the medial retinaculum, tears of the POL or semimembranosis, tears of the VMO muscle or fascia, injuries to the posteromedial knee joint capsule and osseous bruising.

Ligamentous lesions of the MCL may also be associated with displaceable tears of the medial meniscus. Typically, displaceable meniscal tears are complex, large, have a radial component or involve the meniscal root. The displacement is related to an injury to the meniscus that can result in its loss of resistance to hoop strain. It has been recently reported that displaceable meniscal tears may be associated with ipsilateral collateral ligamentous lesions and pain[3]. The authors found displaceable meniscal tears (≥ 3 mm) in 42% of the patients with meniscal tears and that grade two or grade three ipsilateral MCL lesions were present in all 18 displaceable meniscal tears. The patients with a normal MCL and patients that had a grade one lesion were significantly more likely to have nondisplaceable tears ($P < 0.05$). They also found that patients with displaceable meniscal tears had significantly more pain than patients with nondisplaceable meniscal tears ($P < .001$), independent of other abnormalities.

It is important to identify the anatomic location that is injured in patients with medial and posteromedial injuries to the knee as the treatment and rehabilitation will vary according to what is injured. Patients with a proximal disruption of the MCL may be candidates for conservative therapy if the ligament is incompletely torn. If an osseous portion of the femur is avulsed along with the ligament, the injured ligament may be reattached with a suture anchor or screw. Tears of the MCL along the joint line may be repaired with end to end suturing and tears at the level of the tibial insertion may involve the pes anserine tendons thereby necessitating a repair directly to the bony medial tibia and pes anserine foot plate with sutures and/or staples.

Tears of the MCL itself will be characterized by loss of resistance to valgus strain with the flexed to 30 degrees. If the knee is unstable in extension a tear of the POL must be suspected. The ACL and the joint capsule also contribute to medial stability of the knee. Identification of coexisting ACL and MCL tears are important as most ACL repairs are performed only after valgus stability has returned. Typically, the MCL is allowed to heal prior to performing an ACL reconstruction.

Tears of the MCL may be treated conservatively as the torn fibers have a strong tendency to heal without surgical intervention. The fibers heal well then the torn ends of the MCL are in contact with each other and the healing potential is directly related to the size of the gap between the torn ends of the ligament. Non operative treatment is warranted for partial tears and the healing time correlates well with the degree of injury. Non-operative treatment may result in some degree of MCL laxity but this usually has little effect on knee function.

Tears of the POL (figure 2) are important to identify as repair of these lesions may provide long term stability and tears in this location may involve the semimembranosis[4]. Typically, POL tears are reattached to the femoral epicondyle and posterior edge of the MCL. Most tears of the POL are located in the proximal (femoral) portion.

MR imaging may also identify injuries to other structures that may mimic MCL tears and can assess for other associated injuries. The MCL is best visualized on axial or coronal T2-weighted images with fluid sensitive sequences. The oblique coronal plane is optimal for evaluating the POL and this sequence is prescribed from a sagittal localizer is oriented in a 25° posterior oblique plane (along the course of the POL)[5,6]. The medial knee complex is evaluated for anatomic abnormalities and for fluid along the course of the MCL or POL. Tears of the MCL or POL will typically be well seen on MR imaging and are usually not associated with a large joint effusion. The presence of a large effusion should prompt additional assessment for other associated injuries.

Imaging and treatment of PCL injuries

Tears of the posterior cruciate ligament (PCL) typically result from forced hyperextension. As compared with tears of the ACL, PCL tears are typically under recognized. Most of the PCL tears occur near the tibial insertion and isolated tears without other associated injuries are unusual. The first reported PCL reconstruction is attributed to Dr. Hey Groves who performed the procedure in 1917. Reconstruction of the PCL is far less common that reconstruction of the ACL and PCL reconstruction surgery is typically reserved for chronic high grade tears, displaced tears and tears that are associated with osseous avulsions. If the desired goal is to repair a torn PCL, it is most optimal to repair the ligament soon after it has been torn (within 3 weeks or less).

Anatomically, the PCL has anterolateral and posteromedial bundles. The anterolateral band is taut in flexion and the posteromedial band is taut in flexion. The PCL is thicker than the ACL and is approximately twice as strong.

Reconstruction is an effective method of repairing the PCL but the issue of repair vs. conservative treatment is controversial. Unlike the ACL, the PCL has been shown to heal even after severe injury and conservative therapy may lead to a good functional outcome (Figure 3) [7, 10-13]. If conservative therapy is chosen, the time it takes for the ligament to heal can vary widely and ranges from 6 to 20 months.

Various authors have examined the outcome of PCL injuries and the tendency of the PCL to heal. Tewes, et. al. showed that 10 of 13 patients with complete PCL tears regained continuity as established by MR imaging[10]. Shelbourne, et. al. demonstrated that 25 of 37 patients with varying degrees of PCL tears regained continuity of the ligament (also evaluated with MR imaging)[11]. The authors also detected no correlation between the location of the injury and its propensity to heal. There was some degree of correlation between the severity of the injury and whether or not the ligament healed. The healing potential has been estimated at nearly 100% for partial tears and between 62 and 86% for complete tears[10,11]. Imaging of the healed PCL's showed some morphology changes but these changes did not appear to affect the function of the PCL. Overall, the PCL tended not to heal when the tears were complete and associated with an MCL tear or posterolateral complex injury or if the posterior translation of the tibia in relation to its normal position was more than 10-12mm [7-11].

A complete MR evaluation of the PCL is helpful to determine what the preferred treatment method will be. If a tear is a partial tear or is not significantly displaced, it will most likely heal. On the other hand, the tear may not heal if the tear is complete (involves both bundles), is associated with medial or lateral collateral ligament injuries, or if it has more than 10-12mm of posterior translation the PCL tear may require surgical reconstruction.

Detection of Particle Disease after Total Knee Arthroplasty

Particle disease (PD) is a primary factor causing loosening of joint arthroplasties and this process can significantly limit the longevity of the total knee arthroplasty (TKA). The primary material for the metallic components of the TKA is cobalt chrome and the spacer is most commonly made of polyethylene. Other components materials may also be used in place of cobalt chrome including ceramics such as alumina ceramic and oxinium (oxidized metal zirconium). Initial laboratory tests show a decreased amount of particle wear with a ceramic-polyethylene combination.

Particle disease results from prosthesis wear. The particles that are produced from the wear are absorbed by macrophages. The macrophages produce chemoattractants and inflammatory mediators (PGE_2 & IL-1) that stimulate the osteoclasts to resorb the periprosthetic bone.

The detection of particle disease has traditionally been through x-ray evaluation. Nuclear medicine scanning (with Technetium 99-MDP and gallium) and arthrography have been used to detect prosthetic loosening. Typically, MR imaging has not been used for the evaluation of TKA's due to prominent metallic artifacts. Stainless steel components give rise to more prominent artifacts than do titanium or oxidized zirconium[14] but the artifacts from most metallic or ceramic prostheses limit the utility of the typical MR imaging evaluation. This propensity for artifacts has contributed to the common belief that MR imaging is not appropriate for detecting periprosthetic pathology such as loosening or particle inclusion disease in patients with arthroplasties. Various MR imaging techniques, however, have been developed to combat the susceptibility artifacts seen with MR imaging.

Magnetic Resonance imaging has been shown to be accurate in detecting and sizing areas of osteolysis[14] and in evaluating the surrounding soft tissue structures (figure 4). MR imaging after arthroplasty poses particular challenges due to the prominent artifact from the metal prostheses.

Because the artifact from metal is partly due to incorrect spatial encoding resulting from frequency misregistration, widening the receiver bandwidth decreases the apparent size of artifact. This occurs because the widened bandwidth allows a broader range of frequencies to be sampled, so that the difference between any two frequencies is a smaller percentage of the total range. In one study, widening the receiver bandwidth from 16 kHz to 64 kHz reduced metal artifact by 60%[16]. In addition to sampling over a broader range of frequencies, widening the receiver bandwidth also serves to decrease inter-echo spacing. A shorter time of echo (TE) allows less time for intravoxel dephasing than a long TE, and is therefore less sensitive to metal artifact. The down-side of widening the receiver bandwidth is that it causes a decrease in signal to noise (SNR)[17]. To compensate for the loss of SNR, increasing the number of excitations (NEX) may be necessary.

The echo train length (ETL) has also been shown to be a factor in the severity of artifacts[17]. Increasing the number of refocusing pulses (increasing ETL) decreases the time for intravoxel dephasing to occur.

The misregistration from metal implants occurs between slices (in the z-plane) as well as in the frequency encoding direction (y-plane). Similar to the receiver bandwidth, the slice-select bandwidth can be widened by increasing the magnitude of the gradient and decreasing the time in which the gradient is applied. For example, a 20% increase in bandwidth can be achieved by multiplying the gradient magnitude by a factor of 1.2, and decreasing the time in which the gradient is applied by a factor of 1.2[16]. This decreases misregistration between slices.

An additional technique used by some authors to reduce metal artifact is called "view angle tilting" (VAT)[16-18]. This is achieved by re-applying the slice-select gradient at time of readout, so that both the slice-select gradient and the frequency-encoding gradient are applied simultaneously. VAT causes the spins to be aligned essentially tangential to the frequency plane at time of readout, and has been shown to reduce susceptibility artifact[14, 18]. Image blurring is a problem resulting from this technique, and different methods have been attempted to reduce blurring[14]. In one study, a combination of widening the receiver bandwidth, widening the slice-select bandwidth, and applying VAT resulted in decreased artifact compared to either widening the receiver bandwidth or VAT alone[16].

Overall, with use of a few modifications, MRI can be useful and accurate in evaluating the periprosthetic osseous and soft tissue structures after total knee arthroplasty. In the future, MRI may become the image modality of choice for the painful knee prosthesis.

Summary

The current MR imaging classification of tears of the medial collateral ligament has limited utility as it may overestimate low grade lesions, edema in the MCL may be seen with entities other than ligament injury and its simplistic tear grading belies complex MCL anatomy. Isolated tears of the MCL are unusual and an accurate description of the associated injuries is important as what is injured will determine the treatment strategy. Displaceable meniscal tears may be associated with ligamentous lesions of the MCL and can also be associated with medial knee pain. Although surgery is affective for certain types of severe, chronic or displaced PCL tears, most PCL injuries will adequately heal without surgery. A complete MR imaging evaluation is necessary for determining the characteristics of the PCL tear and associated injuries as complete tears, tears with associated MCL or posterolateral complex injuries and tears with more than 10 to 12 mm of displacement may not heal with conservative therapy. Although not typically utilized for evaluation of total joint arthroplasties, MR imaging using certain techniques such as an increased receiver bandwidth, a short TE, an increased ETL, increased slice select bandwidth and view angle tilting is effective at defining the amount of particle disease and may be useful in monitoring the disease process.

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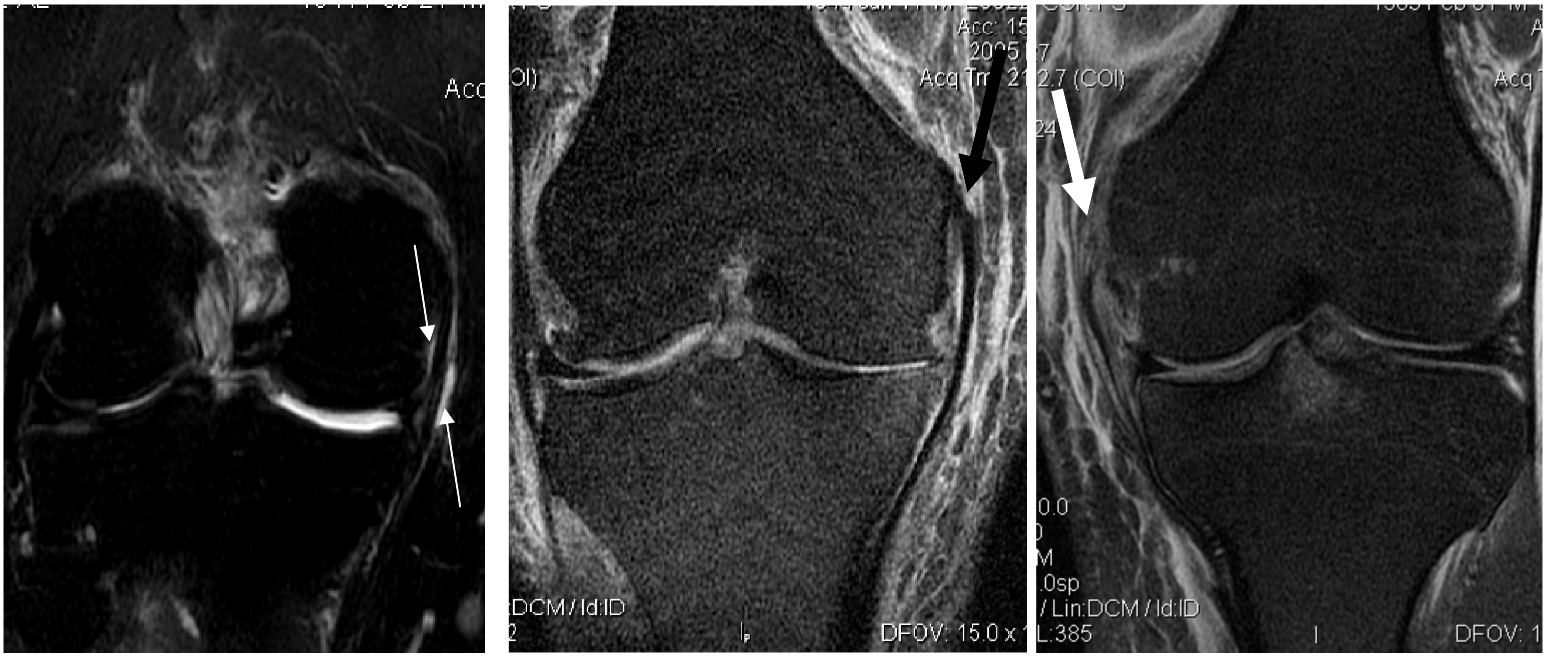
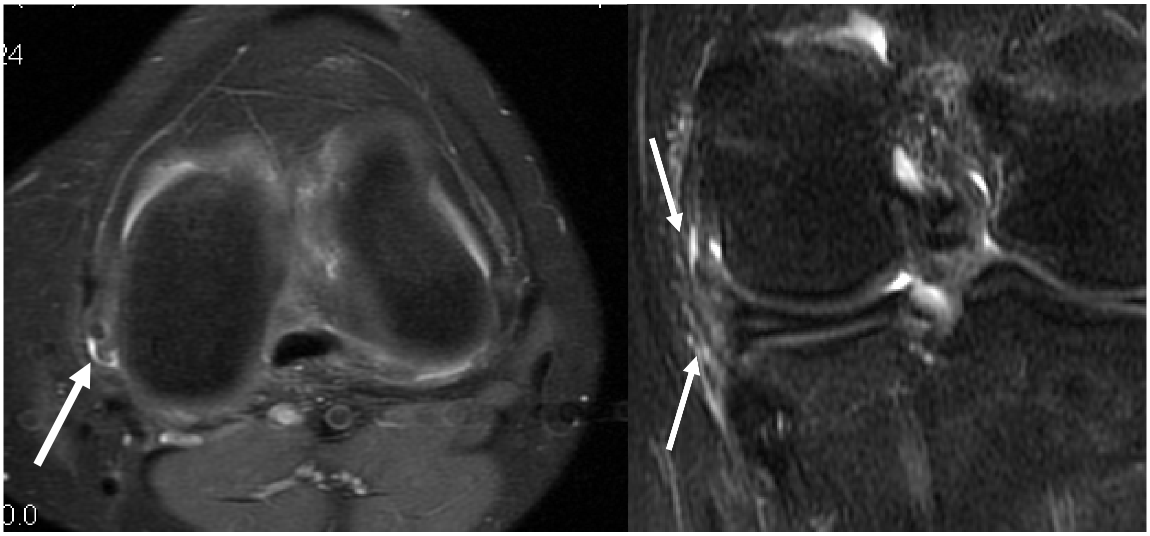
Figures



a. b. c.

Figure 1a-c. Coronal fluid sensitive sequences show varying degrees of MCL injury. Grade one ligamentous tear of the MCL shows fluid surrounding the MCL (white arrows in a) but the ligament fibers are intact. A grade two injury demonstrates partial disruption of the MCL fibers (black arrow in b) but a portion of the fibers of the MCL remain intact. A grade three MCL tear shows complete disruption of the ligamentous fibers (white arrow in c). A complete disruption of the ligament fibers will also be evident on physical exam as prominent laxity and loss of resistance to valgus stress.



a. b.

Figure 2a-b. Axial (a) coronal (b) fluid sensitive sequences demonstrating fluid surrounding the posterior oblique ligament (white arrows) indicative of a partial tear of the POL. The fibers themselves are also irregular as is characteristically seen with a partial ligamentous tear.

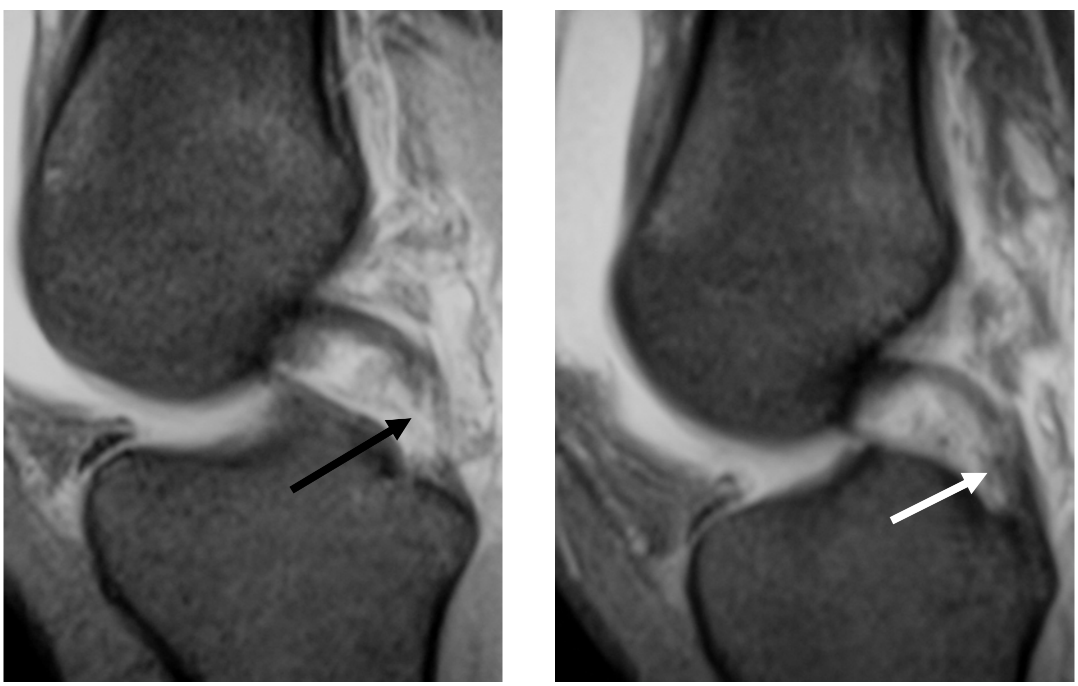


Figure 3 a-b. Sagittal T2-weighted images taken 2 years apart shows a high grade partial tear of the PCL (black arrow in a) that is sown to be healed 2 years later (white arrow in b).

a. b.

Figure 4 a-b. Axial (a) and coronal (b) MR images demonstrating synovitis (black arrow in a) and loosening of the patellar backing (white arrows in a) as well as a joint effusion (black arrowheads). Prominent regions of osteolysis and particle disease burden are noted in the proximal tibia surrounding the tibial component (black curved areas in b).