Knee MRI: Meniscal Tears and Postoperative Cartilage Imaging

Humberto G. Rosas

Currently magnetic resonance (MR) is the modality of choice for assessing the meniscus with reported accuracies, sensitivities, and specificities ranging between 85% to 95% in detecting meniscal tears. Once a tear is identified, it is imperative not only to localize the tear, but to describe the tear pattern, extent, and any associated chondrosis to guide treatment options for the referring physician. The International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) Knee Committee formed a Meniscal Documentation Subcommittee in 2006 with the objective of developing a reliable classification system in the evaluation of the meniscus in order to facilitate outcome assessment. The tear patterns include: longitudinal-vertical, horizontal, radial, vertical flap, horizontal flap, and complex.

Magnetic resonance imaging is also well suited to evaluate postoperative repair tissue given its excellent soft tissue contrast, multi-planar capabilities and ability to visualize not only the articular surface but the subchondral bone plate and underlying bone. Various types of surgical repair techniques have been developed over the past decade to treat cartilage lesions requiring an accurate, noninvasive means of assessing the repair tissue. Although several scoring systems have been developed, the most commonly used is the magnetic resonance observation of cartilage repair tissue (MOCART). The MOCART score is a composite score of 9 individual parameters: defect filling, integration to border zone, repair tissue surface, repair tissue structure, repair tissue signal intensity, subchondral lamina, subchondral bone, adhesions, and effusion.

The purpose of this review is to discuss the imaging criteria for diagnosing meniscal tears, common diagnostic pitfalls, and the most common classification systems currently employed in describing meniscal tears and post-operative cartilage repair tissue.

MR APPEARANCE OF MENISCAL TEARS

The MR criteria for diagnosing a meniscal tear include either increased intrasubstance signal unequivocally contacting the articular surface or meniscal distortion in the absence of prior surgery. If these criteria are present on two or more images, fulfilling the “two touch slice rule,” the specificity increases with a positive predictive value (PPV) of 94% and 96% respectively for medial and lateral meniscal tears and should be reported as a torn meniscus.[1] A common misconception is that the findings must be identified on contiguous slices when in fact if either meniscal distortion or intrameniscal signal contacting the articular surface is identified in the same region on any two MR images including consecutive slices or alternatively on one coronal and one sagittal image, the criteria have been met.[2] If these criteria are present on a single slice, the PPV decreases to 43% and 18% for medial and lateral meniscal tears respectively and should be reported as a possible tear.

As our understanding of both the function of meniscus and deleterious long-term biomechanical effects following meniscetomy increases, treatments both surgical and nonsurgical continue to evolve, placing a greater emphasis on meniscal preservation to maintain normal knee anatomy and reduce the potential

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for accelerated degenerative changes. This places an even greater role on the imaging assessment of internal derangement and the necessity for a standardized classification system.

CLASSIFICATION OF MENISCAL TEARS

Treatment options and surgical techniques vary considerably based on several factors including meniscal tear pattern. Longitudinal tears are often amenable to repair, whereas horizontal tears or partial radial tears typically require debridement. Therefore, it is imperative to not only diagnose a meniscal tear but to provide an accurate morphological description to guide treatment options and assess long term outcome measures. The ISAKOS arthroscopic meniscal tear classification system includes longitudinal-vertical, horizontal, radial, vertical flap, horizontal flap, and complex.

Longitudinal-Vertical Tears

A longitudinal-vertical tear courses parallel to the long axis of the meniscus perpendicular to the tibial plateau and can involve a single articular surface or both articular surfaces separating the meniscus into inner and outer segments (Figs 1 & 2).[3] Peripheral longitudinal tears involving the posterior horn of the lateral meniscus are often difficult to identify due to the complex anatomy and posterior attachments of the meniscus. Disruption of the posterosuperior popliteomeniscal fascicle has a high positive predictive value for arthroscopically confirmed tears of the posterior horn of the lateral meniscus[4] and a far lateral meniscofemoral ligament attachment exceeding 14mm beyond the lateral border of the posterior cruciate ligament likely represents a tear.[5] In our experience, this type of tear can be more conspicuous on the sagittal T2-weighted images. Unlike horizontal or radial tears, pure longitudinal tears do not involve the free edge of the meniscus. Several normal anatomic structures may mimic a longitudinal tear including the popliteus tendon as it courses intra-articularly, the attachment sites of the popliteomeniscal fascicles, transverse ligament, and meniscofemoral ligaments, and the normal striated appearance of the anterior root ligament of the lateral meniscus formed from contributing fibers originating from the anterior cruciate ligament.[6]

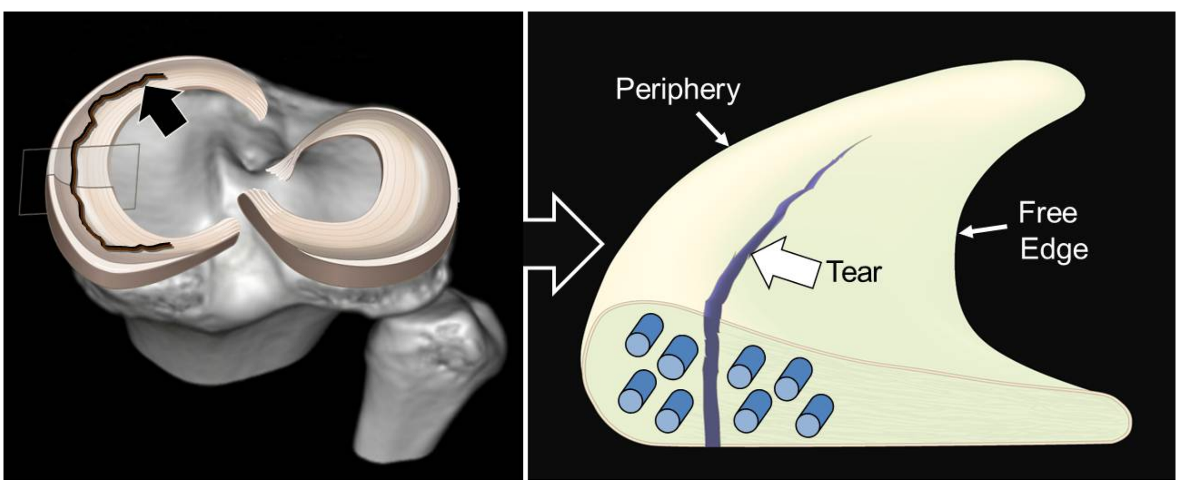

Figure 1. Longitudinal tear. 3-D model (left image) and cross-sectional illustration (right image) show a longitudinal tear (block arrows) running parallel to the long axis of the meniscus and dissecting between the longitudinal collagen bundles.

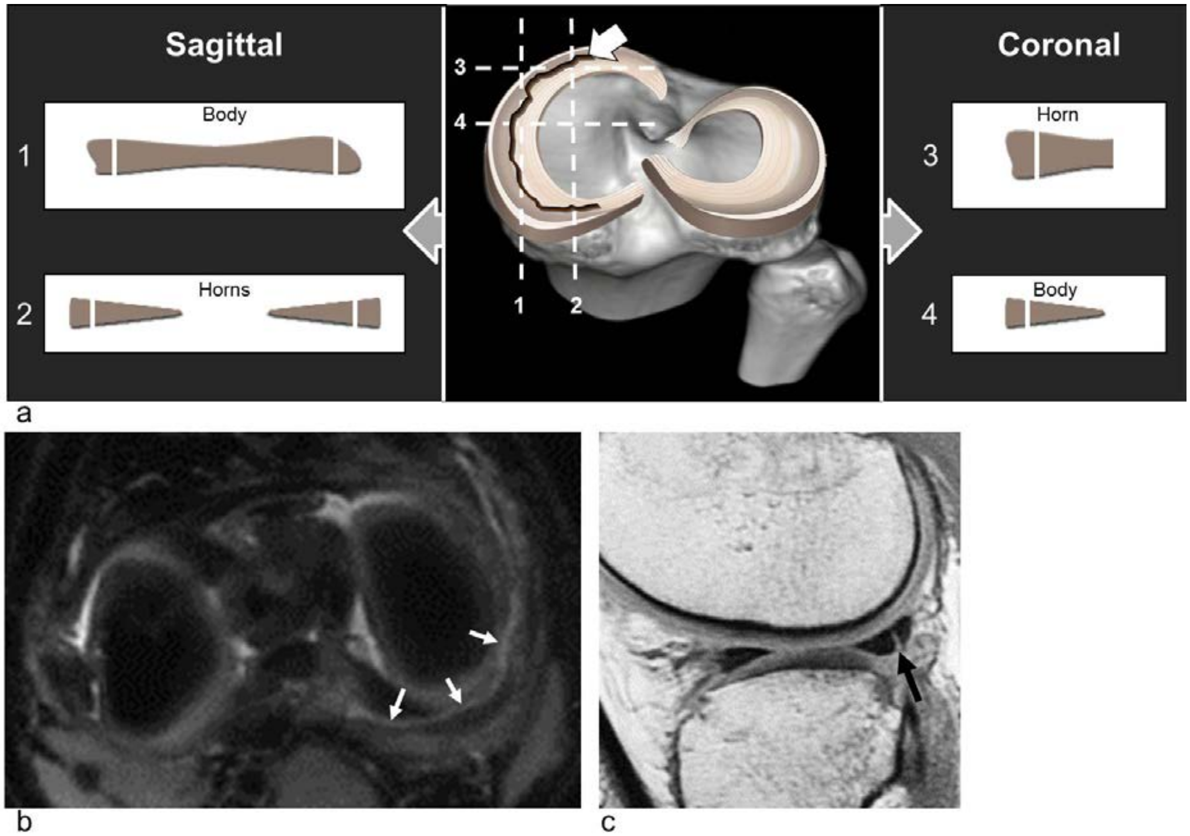

Figure 2. Longitudinal tear. **(a)** 3-D drawing characterizes a typical longitudinal tear (block arrow) dividing the meniscus into inner and outer halves. Illustrations to either side represent the expected imaging appearance on sagittal and coronal sequences. **(b)** Fluid-sensitive axial reformatted image shows a peripheral longitudinal tear involving the posterior body, the posterior horn, and extending into the posterior root (arrows). **(c)** Sagittal PD-weighted image of a peripheral longitudinal tear demonstrates increased intrasubstance signal unequivocally contacting the articular surface in a vertical orientation (arrow). This type of tear should not extend to involve the free edge.

A bucket handle tear represents a longitudinal tear with central migration of the inner segment and is the most frequent type of displaced tear (Fig 3). Several imaging findings have been described with this type of meniscal injury including the absent bow tie sign, double posterior cruciate ligament sign, double anterior horn or flipped meniscus sign, and fragment within the intercondylar notch sign (Fig 4). [7]

Horizontal Tears

A horizontal tear classically involves either the free edge or one of the articular surfaces and propagates peripherally separating the meniscus into upper and lower halves (Figs 5 & 6).

Meniscal cyst formation is associated with horizontal tears which extend to the periphery, presumably secondary to direct communication with the joint fluid.

Radial Tears

A radial tear involves the free edge of the meniscus but, in contrast to horizontal tears follows a path perpendicular to the long axis of the meniscus dividing the meniscus into anterior and posterior portions. (Fig 7) These injuries disable the ability of the meniscus to resist hoop stress as the circumferential fibers are sequentially disrupted. These tears are infrequently amenable to repair given the low likelihood of regaining function.

Radial tears commonly involve the posterior horn of the medial meniscus or the junction of the anterior horn and body of the lateral meniscus. Various imaging signs describing a radial tear include the truncated triangle sign, the cleft sign, and the ghost meniscus (Fig 8).[8] The variable appearance is dependent on the location of this type of tear relative to the imaging plane.

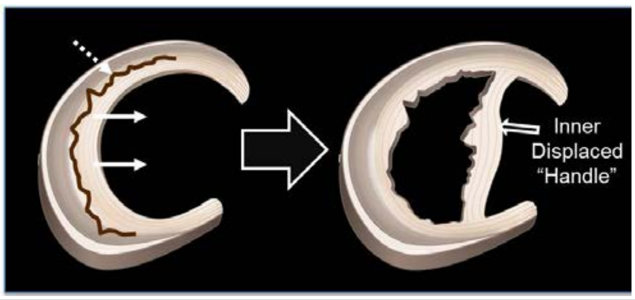

Figure 3. Bucket-handle tear. 3-D illustration of a bucket handle tear. Classically these represent a longitudinal tear (dashed arrow) with central displacement of the inner segment.

Flap Tears (Fig 10)

Horizontal or vertical flap tears represent tears in which the configuration permits an unstable fragment of meniscal tissue to displace into the periphery of the joint while remaining connected with the remainder of the meniscus. Clinical manifestations include mechanical obstruction in the form of locking or catching. Preoperative identification is imperative as displaced fragments may be difficult to visualize arthroscopically and require the use of a probe or hook to localize and reduce. In the vast majority of cases, the meniscal fragment can be localized either within the posterior intercondylar notch or the gutters. These tears occurs more commonly in the medial meniscus where the fragments are displaced in two thirds of the cases along the posterior intercondylar notch near or posterior to posterior cruciate ligament with the remaining cases seen with a fragment coursing into one of the recesses of the medial gutter. With the lateral meniscus, fragments are present with equal frequencies along the posterior joint line and lateral recess. [9] As a rule, in the absence of prior surgery, if a meniscus appears blunted, a careful search for a displaced fragment should be performed.

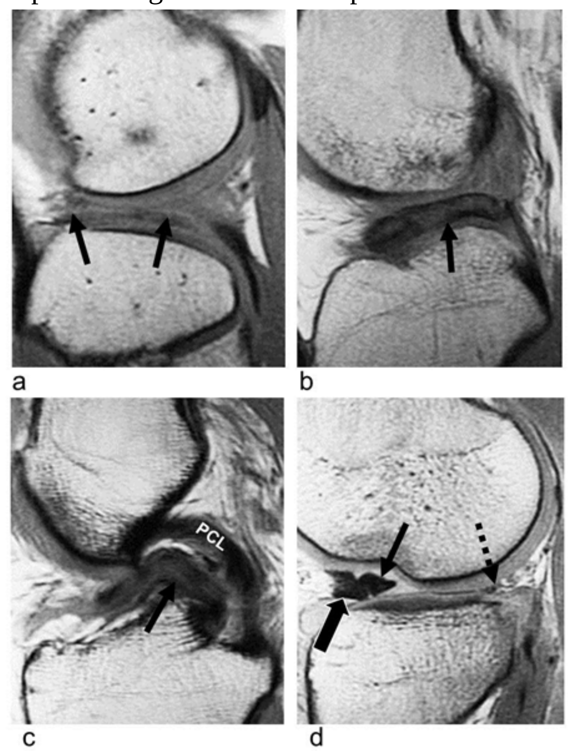

Figure 4. MR imaging signs of bucket-handle tears. **(a)** Absent bowtie sign denotes the non-visualization of the meniscal body (arrows). **(b)** Fragment within the intercondylar notch sign shows a centrally displaced meniscal fragment (arrow), which is eccentric to the PCL. **(c)** Double PCL sign shows a displaced fragment (arrow) of the medial meniscus located anterior and parallel to the PCL. **(d)** Double anterior horn sign with a meniscal fragment (arrow) posterior to and displacing the native anterior horn (block arrow) in addition to a markedly diminutive posterior horn (dashed arrow).

Root Tears

Although often described as a subtype of radial tear, they often represent a more complex injury. The ISAKOS classification system can be utilized to describe tears in this location, however the unique anatomy of the posterior root ligaments and their undulating course along the tibial slope predispose to diagnostic dilemmas owing to MR magic angle effect compounded by pulsation artifacts. Unlike the situation for most tear types, coronal and fluid-sensitive sequences allow better definition of the roots and partially compensate for the aforementioned artifacts.[10] On the coronal images, the roots should drape over their respective tibial plateau on at least a single image. On sagittal images, if the posterior root of the medial meniscus is not identified just medial to the PCL, one should suspect a root tear. If identified preoperatively, this can direct surgical treatment and surgical technique as the posterior roots are not easily accessible at the time of arthroscopy and require placement of additional portals for adequate visualization.

Root tears are associated with meniscal extrusion and linear subchondral edema.[11] Extrusion is present if the peripheral margin of the meniscus extends more than 3mm beyond the edge of the tibial plateau on a midcoronal image on which the MCL is visible. 76% of medial root tears demonstrate a component of extrusion.

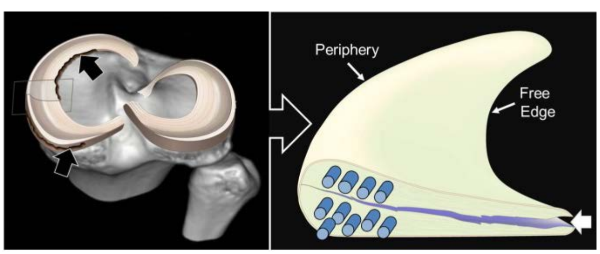

Figure 5. Horizontal tear. 3-D model and cross sectional illustration of a horizontal tear (block arrows) separating the meniscus into upper and lower halves.

Complex Tears

A tear composed of a combination of either radial, horizontal, or longitudinal components may be classified as a complex tear. Commonly the meniscus appears fragmented with the tear extending into more than one plane.

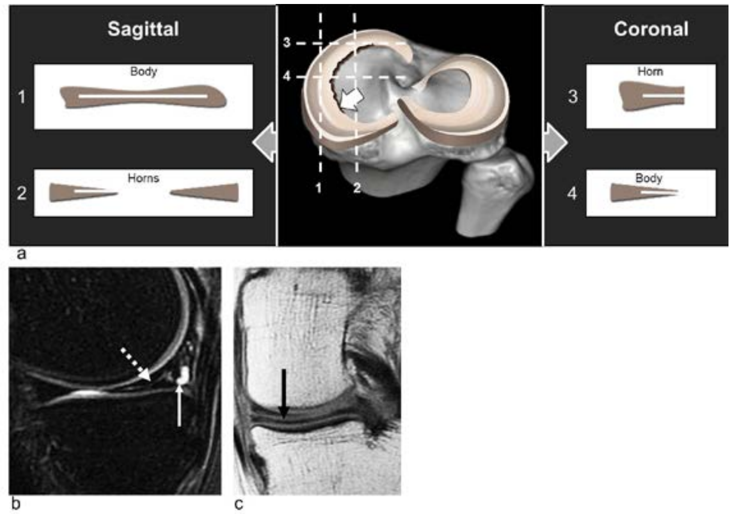

Figure 6. Horizontal tear. **(a)** Representative illustration of a horizontal tear (block arrow) and expected MR appearance based on the imaging plane (right and left insets). **(b)** Sagittal T2-weighted image shows a tear of the posterior horn (dashed arrow) with an associated multiloculated parameniscal cyst (white arrow). **(c)** Coronal PD-weighted image of a horizontal tear of the body (arrow), which contacts the superior articular surface.

ANATOMIC VARIANTS

Two anatomic variants distort the meniscal shape and may cause a false-positive diagnosis of a tear – a discoid meniscus and a meniscal flounce. A discoid meniscus represents an enlarged meniscus diagnosed on MR imaging when the body measures 15mm or greater on a midcoronal image. Watanabe and Takeda describe three subgroups: (i) the complete variant is a block-shaped meniscus which covers the entire tibial plateau; (ii) the partial variant covers 80% or less of the tibial plateau; and (iii) the Wrisberg variant which has altered or absent posterior attachments resulting in a hypermobile meniscus often presenting clinically as the sensation of a “snapping” knee.[12]

Meniscal tears are more common with the complete variant. MR unfortunately has widely variable sensitivities and specificities due to the increased vascularity and diffuse intrameniscal signal in discoid menisci. Therefore, the diagnosis of a tear relies more heavily on morphological distortion rather than abnormal MR signal intensity. Diffuse intrameniscal signal extending to the articular surface has been shown to have a poor positive predictive value (57-78%) in the setting of a discoid meniscus. Therefore, currently we report a discoid meniscus with diffuse signal contacting the articular surface as a possible tear (60-80% likelihood). Linear signal unequivocally contacting the articular surface however typically represents a meniscal tear.

A meniscal flounce is a rippled appearance of the free, non-anchored inner edge of the medial meniscus. The distortion does not indicate a tear, although the result may be the appearance of a truncated meniscus on coronal images similar to a radial type tear. Typically this is secondary to flexion at the knee joint and redundancy of the free edge of the meniscus.[13]

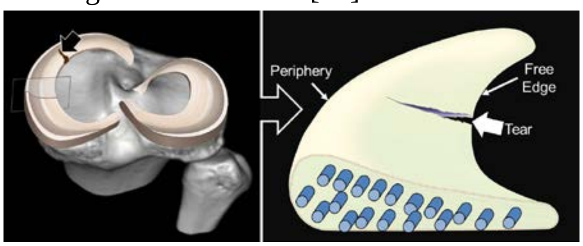

Figure 7. Radial tear. 3-D model and cross-sectional illustration show a partial-thickness radial tear (block arrows) involving the free edge, running perpendicular to the long axis of the meniscus.

POSTOPERATIVE CARTILAGE IMAGING

Cartilage injuries are a frequent cause of pain and are detected in 63% of arthroscopies. Due to the relative avascularity of the articular cartilage these lesion do not spontaneously heal and must be surgically repaired. The current main surgical repair options used in clinical practice include bone marrow stimulation techniques such as microfracture, tissue based cartilage repair techniques typically utilizing osteochondral plugs, or cell based cartilage repair techniques with implantation of harvested chondrocytes as seen with autologous chondrocyte or matrix associated chondrocyte implantation.

MRI is the imaging modality best suited to provide an objective, reproducible, and noninvasive means of assessing and monitoring repaired cartilage tissue given its superior soft tissue contrast. Various MRI scoring systems are described in the literature with the most commonly used being the magnetic resonance observation of cartilage repair tissue (MOCART) classification system. [14]

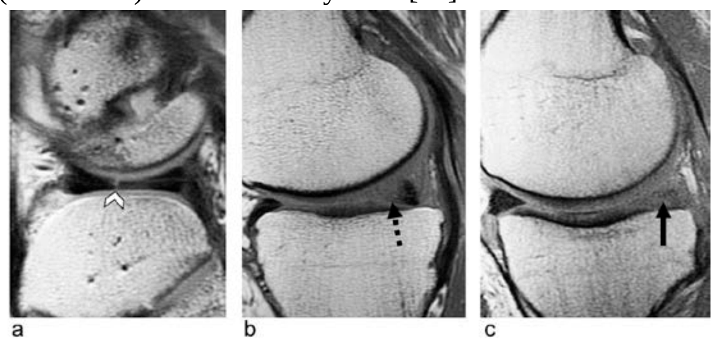

Figure 8. MR signs of radial tears. **(a-c)** Sagittal PD-weighted images demonstrating the cleft sign (a), truncated meniscus sign of a partial thickness tear (b), and a ghost meniscus (c) associated with a full thickness radial tear. Each of these tears involves the free edge of the meniscus

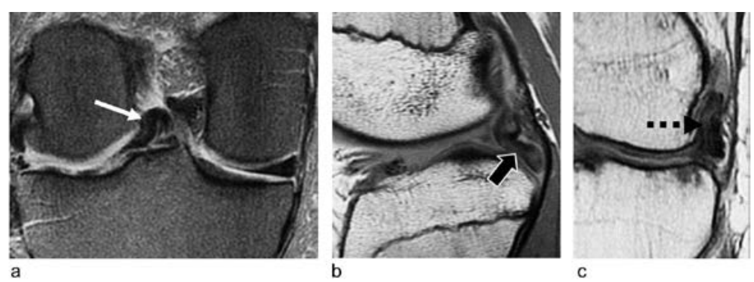

Figure 9. Flap tears. **(a)** Coronal T2-weighted image shows a flipped fragment within the posterior intercondylar notch (arrow) from a horizontal tear of the MM. **(b)** Sagittal PD-weighted image shows a large fragment (block arrow) flipped into the popliteus recess from a torn lateral meniscus. **(c)** Coronal PD-weighed image of a displaced meniscal fragment extending into the superior recess of the lateral gutter.

MOCART

This system evaluates nine parameters: degree of defect filling, integration of the repair tissue with the native cartilage along the border zone, surface congruity, structure of the repair tissue, signal intensity of the repair tissue, integrity of the subchondral lamina, condition of the subchondral bone, the presence of adhesions and the presence or absence of a joint effusion. Studies have shown good interobserver variability for scoring defined variables when using the MOCART system and it provides an effective means of standardizing reports. The appearance of the cartilage repair tissue and MRI findings however are influenced by the specific type of procedure performed and the time interval between surgery and imaging.

Therefore, when interpreting studies following a cartilage repair technique, the interpreting physician must be cognizant that many of MRI findings such as subchondral edema, joint effusion, hyperintense repair tissue signal, and incomplete defect fill, among others are part of the normal reparative process in the early postoperative period (Fig 10). In general the majority of "abnormal" findings should normalize at approximately one year following surgery. [15]

A general understanding of the various repair techniques and associated imaging parameters that best correlate with clinical outcomes is also of the utmost importance. Bone marrow stimulation procedures such as microfracture require debridement of the unstable cartilage followed by penetration of the subchondral bone with the use of an awl or drill allowing pluripotent stem cells from the bone marrow to form a fibrin clot within the defect. Over time, the clot differentiates and fills the defect with fibrocartilage. The strongest correlation with surgical outcomes is defect fill.[16]

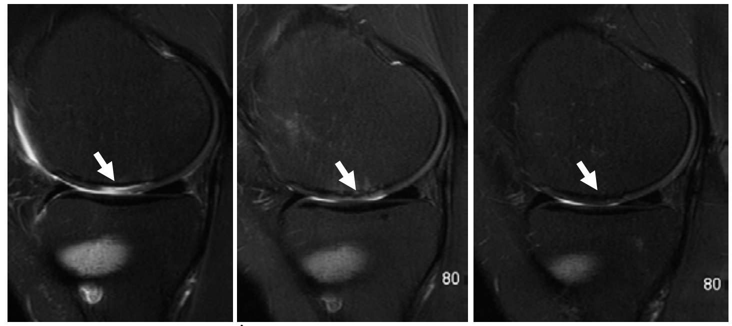

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Figure 10. Normal repair process following a microfracture procedure. **(a)** Initial MRI examination demonstrates a large chondral defect along the weight bearing surface with a chondral flap (arrow). **(b)** 8 months post-procedure the defect has filled in with slightly hyperintense fibrocartilage and minimal surrounding subchondral edema. **(c)** Subsequent scan at the 18 month interval shows maturation of the fibrocartilage and resolution of the bone marrow edema.

Tissue repair techniques typically entail the harvesting of osteochondral plugs which are subsequently transplanted into the articular defect. The goal of the procedure is to restore the normal radius of curvature of the articular surface to maintain biomechanical integrity. Both proud and recessed plugs have been shown to have the worse long term outcomes, felt to be attributed to mechanical stress.

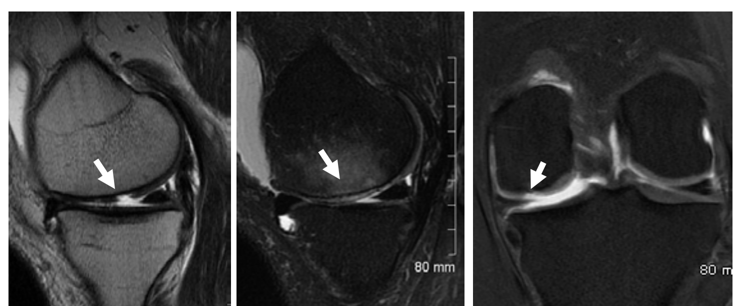

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Figure 11. Poor surgical outcome. **(a)** Initial MRI demonstrates a chondral defect along the weight bearing surface of the medial femoral condyle (arrow). **(b)** & **(c)** 18 months following a microfracture the fibrocartilage has failed to normalize and continues to be hyperintense in signal relative to the native hyaline cartilage. Additionally there is persistent bone marrow edema and either incomplete fill or development of a cartilage ulcer along the posterior margin (best visualized on the coronal image).

Cell based cartilage repair techniques involve the harvesting of chondrocytes which are cultured, replicated, and loaded onto a membrane to be placed into the articular defect. Defect fill correlates best with clinical outcomes.

CONCLUSION

Imaging plays an important and expanding role in the diagnosis of meniscal injuries and assessment of cartilage repair tissue. An understanding of the diagnostic criterion and classification systems will not only allow a more accurate and standardized assessment of the imaging findings, but provide a means to conduct research on outcome measures and guide treatment regimen.

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