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The Quality of MRI in Meniscal Tears

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Abstract: ***This article summarizes my research and clinical experience in the diagnosis of meniscal tears using knee MRI. I have referenced the recent literature and give my opinions as well as unpublished clinical observations when definitive research is not available on specific topics. When evaluating a knee MR examination, I study the medial and lateral menisci first on the sagittal images and then on the coronal images because sagittal images are the most useful in diagnosing meniscal tears. In one study, 95% of medial and 90% of lateral meniscal tears could be identified on sagittal MR images. In a later study, 82% of meniscal tears were definitively diagnosed on sagittal images alone. Menisci should have low signal intensity on MR images because of their fibrocartilage composition, but they may have central globular or linear increased signal intensity secondary to internal mucinous degeneration. In addition, the menisci in asymptomatic children have a 66% frequency of internal signal on MRI and that signal is presumed to reflect normal vascularity. Another proposed cause of increased intrameniscal signal is a meniscal contusion after acute trauma. I reserve the diagnosis of meniscal contusion for menisci with internal signal equal to fluid on T2-weighted images in patients with a recent episode of trauma. Knowing the distribution of meniscal tears is helpful in assessing the menisci on MRI. In an arthroscopic series of 1086 medial meniscal tears, the posterior horn was involved in 98% of the torn medial menisci. Because of this tear distribution, I am cautious in diagnosing a medial meniscal tear that does not involve the posterior horn. However, lateral meniscal tears are more varied in location: Investigators who conducted an arthroscopic series of 399 lateral meniscal tears reported that tears involved the posterior horn in 55%, the body or the body and anterior horn in 30%, and the anterior horn alone in 15%. The Quality of MRI In Meniscal Tears :Despite the improvement in the quality of knee MR images in the past 25 years, the two primary MR criteria for the diagnosis of meniscal tears have not changed since the late 1980s. These criteria are, first, contact of intrameniscal signal with the superior or the inferior surface of a meniscus (or with both surfaces) and, second, distortion of the normal appearance of a meniscus. To diagnose a meniscal tear using these criteria, it is essential to understand how normal variations in the shape of the menisci and their attachments compare with the MR appearance of a meniscal tear.***

Keywords: Quality of MRI, Meniscal Tears

1. Normal Anatomy

Menisci:
A meniscus is a piece of cartilage found where two bones meet (joint space). Menisci (plural of meniscus) protect and cushion the joint surface and bone ends. In the knee, the crescent-shaped menisci are positioned between the ends of the upper (femur) and lower (tibia) leg bones.The menisci function to absorb shock, distribute axial load, assist in joint lubrication, and facilitate nutrient distribution.

Normal Shape and Attachments of the Medial Meniscus:
The anterior horn, body, and posterior horn of the menisci have a triangular cross-sectional appearance on both coronal and sagittal MR images. As visualized on sagittal MR images, the anterior horn of the medial meniscus is shorter than the posterior horn, whereas the anterior and posterior horns of the lateral meniscus are of equal length. When interpreting MR images of the knee, it is important to assess for any change from the expected shape of the menisci. The anterior and posterior horns of both menisci and the body of the lateral meniscus have an isosceles triangle appearance, whereas the body of the medial meniscus has an equilateral triangle appearance and is shorter than the anterior horn. Normally the superior and inferior surfaces of the menisci are equal in length. A change from this configuration suggests the presence of a tear . However, a meniscus can exhibit a "meniscal flounce," which is a rippled appearance similar to a ruffled item of clothing . A meniscal flounce is uncommon on MRI, being seen in only 0.20% of medial menisci and 0.05% of lateral menisci in one clinical series. However if the knee is flexed, a flounce can be seen on MRI in 5% of menisci. During knee arthroscopy, a flounce is almost always noted in an intact medial meniscus because the knee is flexed during the procedure.

Anterior Root of the Medial Meniscus:
The cross-sectional shape of the medial meniscus changes in the regions of the anterior and posterior roots. The medial meniscus becomes flattened as it transitions into the anterior root. The anterior root has a variable attachment, with 82% of individuals having an attachment on the flat surface of the tibia anterior to the tibial eminence. Three percent of individuals do not have an anterior root attachment to the tibia, but the meniscus is stabilized by the transverse meniscal ligament connecting the anterior horns of the medial and lateral menisci. The most distinctive normal variant—seen in 20% of individuals—is an anterior root attachment on the anterior margin of the tibia near the midline. As a result of this anterior attachment, the meniscus at the midportion of the medial tibial plateau lies anterior to the tibial margin suggesting pathologic anterior subluxation. This subluxation is a normal variation without proven clinical significance.

Posterior Root of the Medial Meniscus:
As the posterior horn of the medial meniscus extends toward its root attachment, it

also loses its isosceles triangular shape. Initially, it becomes a shortened triangle and then flattens at the attachment. As a normal variation, the posterior root may have a fissured appearance that should not be mistaken as evidence of a meniscal tear.

When visualized on coronal images, the posterior root appears as a band of low signal intensity with parallel sides that attaches to the tibia behind the tibial eminence either horizontally or with an inferiorly directed band.

Normal Shape and Attachments of the Lateral Meniscus:
The lateral meniscus has an isosceles triangle appearance in its anterior horn, body, and posterior horn but has considerably more complex anterior and posterior attachments than the medial meniscus. Transverse Meniscal Ligament The transverse meniscal ligament, also called the "geniculate ligament," extends from the anterior horn of the medial meniscus to attach to the anterior horn of the lateral meniscus . At the attachment of the ligament onto the superior surface of the anterior horn of the lateral meniscus, there is commonly a high-signal-intensity line. This line can be mistaken for an anterior horn tear. Anterior Root of the Lateral Meniscus The anterior root of the lateral meniscus differs from the anterior root of the medial meniscus because it often has a prominent fissured appearance similar to the posterior root of the medial meniscus. This fissured appearance on MRI is caused by fibrofatty tissue interposed between the insertional collagenous fibers of the anterior root as well as interposed fibers of the ACL insertion. I have noted that the anterior horn can have a horizontal division as it passes to the root, although this finding has not been described to date in the literature.

Popliteomeniscal Fascicles of the Lateral Meniscus:
The major attachments of the posterior horn of the lateral meniscus are the popliteomeniscal fascicles and the meniscofemoral ligaments. The popliteomeniscal fascicles are fibrous bands covered by synovium that attach the posterior horn of the lateral meniscus to the joint capsule. The most commonly described popliteomeniscal fascicles are the anteroinferior, posterosuperior, and posteroinferior. The anteroinferior and posterosuperior fascicles were seen on MRI in 95% of patients who had a normal lateral meniscus at arthroscopy . That same study found that the fascicles are best seen on T2-weighted images but that the frequency of visualization was not changed in the presence of an effusion. Disruption of these fascicles in a cadaver study was shown to cause meniscal instability. The posteroinferior fascicle extends from the inferior margin of the lateral meniscus at the medial edge of the popliteal hiatus. Because the fascicle is seen in cross section as it passes from the meniscus to its capsular insertion, it may resemble an inferior torn flap of the meniscus . The major landmark that can be used to identify these fascicles is the popliteal hiatus. The hiatus is the opening in the posterior capsule through which the popliteus tendon enters into the joint behind the lateral meniscus. At the medial aspect of the hiatus, the popliteus tendon passes just superior to the posteroinferior fascicle. Then, as the tendon passes laterally, it passes beneath the posterosuperior fascicle and above the anteroinferior fascicle.

Meniscofemoral Ligaments of the Lateral Meniscus:
The other major attachments of the posterior horn of the lateral meniscus are the meniscofemoral ligaments with the Humphry ligament anterior to the posterior cruciate ligament (PCL) and the Wrisberg ligament posteriorly. Both ligaments are routinely identified in anatomic dissections of the knee but only one or both ligaments may be identified on MR examinations of patients. Because these ligaments arise from the lateral meniscus before their attachment onto the inner margin of the medial femoral condyle, they can appear as an apparent cleft or distortion in the superior aspect of the posterior horn. Occasionally the meniscofemoral Humphry ligament can appear as a large low-signal-intensity structure within the notch that may resemble a displaced meniscal fragment. Following the course of the ligaments on sequential sagittal MR images allows differentiation of the normal ligament from a meniscal tear or displaced fragment.

Posterior Root of the Lateral Meniscus:
The posterior root of the lateral meniscus is a particularly difficult area to assess on MRI for a tear. As the posterior horn extends medially into the root, the meniscus rises from the level of the lateral tibial plateau to attach more superiorly on the tibial eminence. This superiorly directed course can result in increased signal on MRI within this area of the lateral meniscus because of the magic angle effect seen in collagen fibers, which are oriented obliquely to the magnetic field. In addition, the posterior root is oriented at 45° to the sagittal and coronal planes so that any abnormality of the root is not visualized in the optimal right-angle orientation to the image planes . As the lateral meniscus passes over the lateral tibial spine toward its attachment, it has a crescentic appearance and then appears as a thin band at its attachment. I have found that fluid-sensitive images are more specific than proton density–weighted images for diagnosing lateral posterior root tears. Proton density–weighted images often show increased signal in the root due to the magic angle effect and the oblique orientation of the root to coronal and sagittal images.

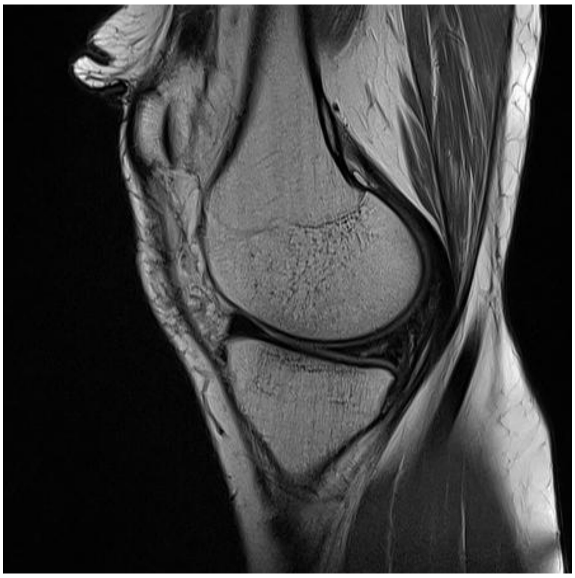
MR Imaging–based Diagnosis of Meniscal Tears
The prevalence of meniscal tears increases with age, and meniscal tears are often associated with and contribute to degenerative joint disease. Tears are more common in the posterior horn of the menisci, particularly favoring the more constrained MM. However, in younger patients with an acute injury, LM tears are more common. Isolated tears in the anterior horn are uncommon, accounting for 4% and 20% of MM and LM tears, respectively . In the presence of ACL tears, there is an increased prevalence of peripheral tears and a decreased sensitivity for detection of LM tears at MR imaging (69% sensitivity, compared with 94% sensitivity in patients without ACL tears). Therefore, special attention should be directed to this location, where a subtle peripheral tear may be present . MR imaging is a proved, highly accurate modality for detection of meniscal injuries, with excellent arthroscopic correlation . Normal menisci should have low signal intensity at MR imaging; however, globular or linear increased intrameniscal signal intensity can be seen in children (due to normal vascularity), in adults with internal mucinous degeneration, and after trauma due to acute contusion. The findings must be identified in the same area

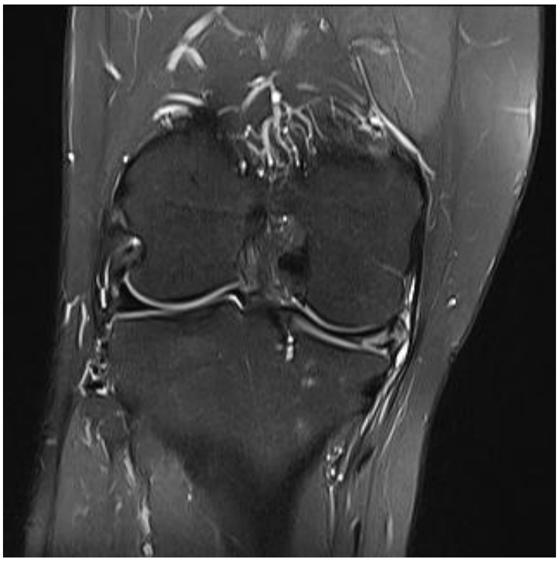
on any two consecutive MR images, which can be two coronal images, two sagittal images, or one coronal and one sagittal image. If these criteria are present on only one image, then the PPV for a tear is 43% in the MM and 20% in the LM, and the finding is best reported as a possible tear . This latter description gives the referring clinician flexibility in managing these cases. In contrast, increased intrasubstance signal intensity without extension to the articular surface is often not associated with a tear at surgery , nor has this finding been shown to progress to a tear . Although most tears can be confidently diagnosed on sagittal images, coronal images are important for confirming and accurately characterizing various tear patterns. Small radial tears, horizontal tears of the body, and bucket-handle tears may be difficult to reliably detect on sagittal images because of volume averaging; these tears may be better depicted on coronal images. In addition, axial images may be helpful for detection of small radial tears, displaced tears, and peripheral tears of the LM posterior horn.

Meniscal Tear Classification

Meniscal tears can be treated with conservative therapy, surgical repair, or partial or complete meniscectomy. Longitudinal tears are often amenable to repair, whereas horizontal and radial tears may require partial meniscectomy. Hence, when a tear is identified, accurate description of its morphology and tear pattern is critical for treatment planning. Currently, there is no standard tear classification system. The most common tear patterns described are horizontal, longitudinal, radial, root, complex, displaced tears.

Horizontal Tears





Horizontal tears are common, representing 40% of the medial and lateral meniscal tears. in a series of 2179 knee arthroscopy patients . Although these tears are often confined to the posterior horn, they may extend into the body and anterior horn of the meniscus. Patients with horizontal meniscal tears often recall no specific episode of trauma but report new or increased knee pain after increased physical activity. Because these tears usually occur in patients more than 40 years old without an initiating trauma, they are sometimes classified as degenerative tears. However, it is better to describe the pattern of tear rather than use a term ascribing a cause to the tear. Histologic studies of cadaveric menisci with MR correlation have found that internal meniscal signal is caused by collagen fiber degeneration with myxoid and eosinophilic deposits . Early reports on meniscal MRI suggested that the increased frequency of internal meniscal signal with increasing age was a precursor to the development of a horizontal tear. However, multiple studies subsequently found that patients with intrameniscal signal on MRI do not have an increased likelihood of developing a meniscal tear or significant knee disability compared with patients without internal meniscal signal on MRI. Horizontal tears appear on MRI as a horizontally oriented line of increased intrameniscal signal that extends to the superior or inferior surface of the meniscus near the free edge. The surface extension may be subtle in some patients because these tears have extensive fibrillation on the surface. This fibrillation results in interdigitated surface fibers so the internal signal may not definitely contact the meniscal surface on MRI. When it is difficult to be certain of surface contact of the internal signal, I am more confident of the diagnosis of a horizontal meniscal tear when the intrameniscal signal has the intensity of fluid on T2-weighted images .

Longitudinal Tears

Longitudinal tears have a vertical orientation on MR images of the menisci and extend parallel to the circumference of the meniscus. These tears are almost always associated with a significant knee injury, especially an ACL tear. In one study, 17% of patients with an acute ACL tear had a medial meniscal peripheral longitudinal tear and 10% had a lateral peripheral longitudinal tear with these tears often having a bucket-handle displacement. Longitudinal tears almost always involve the posterior horn in both the medial and lateral menisci. They are diagnosed on MRI by the presence of a vertical line of increased signal intensity contacting the superior, inferior, or both surfaces of the meniscus. It is sometimes difficult to identify peripheral longitudinal tears in the posterior horn of the lateral meniscus because of the complex posterior attachments of the meniscus.

In these cases, the tear is often more conspicuous on sagittal T2-weighted images. In addition, there are several MR findings that suggest the presence of a lateral meniscal tear. Disruption or the absence of the posterosuperiorpopliteomeniscal fascicle has a 79 100% positive predictive value for an arthroscopically confirmed tear of the posterior horn of the lateral meniscus . In another study, a peripheral longitudinal tear of the lateral meniscus was likely if the meniscofemoral ligament attachment to the lateral meniscus extended 14 mm or more lateral to the PCL. The central fragment of a meniscus with a peripheral longitudinal tear may displace centrally into the joint creating a bucket handle tear. The displaced fragment is considered to resemble the lifted up handle of a bucket. Various signs have been used to describe this centrally displaced fragment including the double PCL sign and flipped meniscus sign.

Radial Tears

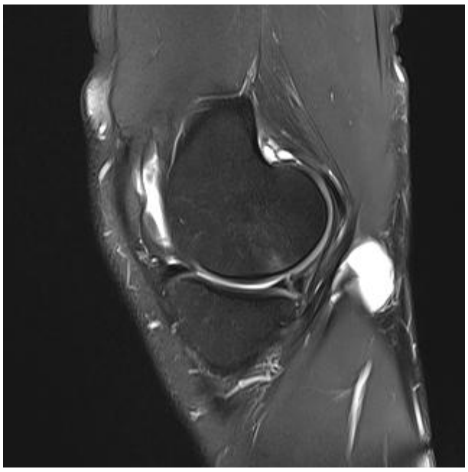
Radial tears are vertically oriented tears that arise from the free edge of a meniscus and extend into the meniscus. Various signs have been used to describe the appearance of a radial tear on MRI including the “cleft” sign, “truncated meniscus” sign, “ghost meniscus” sign, and “marching cleft” sign. The most common locations for radial tears are the posterior horn in the medial meniscus and at the junction of the body and anterior horn in the lateral meniscus. Radial tears in the posterior horn of the medial meniscus are diagnosed on MRI by noting a vertical cleft of increased signal intensity contacting the meniscal surface on coronal images and a blunted or absent meniscus on sagittal images. A radial tear in the medial meniscus is often associated with medial extrusion of the body of the medial meniscus beyond the margin of the tibia. The body of the medial meniscus extrudes because a radial tear disrupts the circumferential fibers of the meniscus. These fibers act like hoops on a wooden stave barrel and resist the outward stresses on the meniscus when bearing weight on the knee. With disruption of the fibers by a radial tear, the body of the meniscus is displaced medially. When the periphery of the body of the medial meniscus is displaced 3 mm or more beyond the edge of the tibial plateau, meniscal extrusion is present. When medial meniscal extrusion is noted on MRI, the posterior horn and root of the medial meniscus should be carefully evaluated for a radial tear. Radial tears at the junction of the body and anterior horn of the lateral meniscus may be difficult to diagnose on MRI because of the oblique orientation of the tear relative to the coronal and sagittal plane images.

My colleagues and I have found that these tears are easier to diagnose now that we have decreased the image interslice gap from 1.5 to 0.5 mm and decreased the image thickness from 3 to 2 mm on the 3-T knee scans. Investigators have reported that thin axial MR images may be helpful in the diagnosis of all types of meniscal tears. However, in my experience, 0.8- to 1.0-mm axial images have been useful primarily in confirming radial tears suspected but not definitively diagnosed on coronal and sagittal images.

Root Tear

A root tear is typically a radial-type tear. Complete root tears have a high association with meniscal extrusion, particularly when the tear occurs in the MM. Root tears have received increased recognition in recent years, partially because of their previous under diagnosis at both MR imaging and arthroscopy. However, if attention is directed to the roots, the sensitivity and specificity for tear detection at MR imaging increase to 86%–90% and 94%–95%, respectively (16,60). Coronal fluid-sensitive MR imaging sequences allow better definition of the roots, which partially compensates for magic angle and pulsation artifacts. On coronal MR images, the root should course over its respective tibial plateau on at least one image. On sagittal MR images, if the posterior root of the MM is not detected just medial to the PCL, a root tear should be suspected. In addition, when an ACL tear is present, there is an increased incidence of lateral root tears. Acute root tears without significant underlying degenerative changes are often promptly repaired because the surrounding rich synovial blood supply facilitates postoperative healing.

Complex Tears



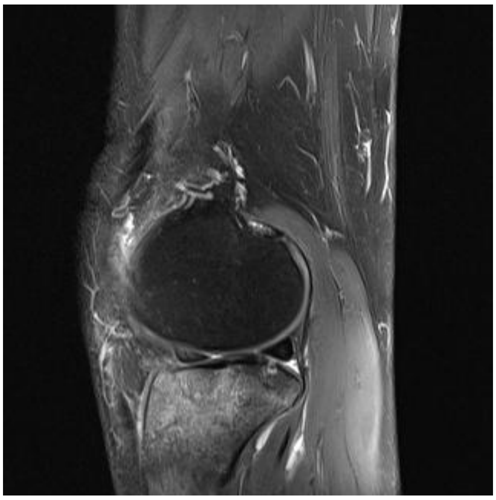
Complex meniscus tears are those in which the tear extends in more than one plane creating separate flaps of meniscus . However, many meniscal tears have a small component of a tear that extends into a second plane. In these situations, I describe a tear as having one predominant plane with a small component in a second plane. I reserve the term “complex tear” for a tear that has extensive distortion and multiple lines of signal to the meniscal surface indicating that multiple flaps will be found at arthroscopy.

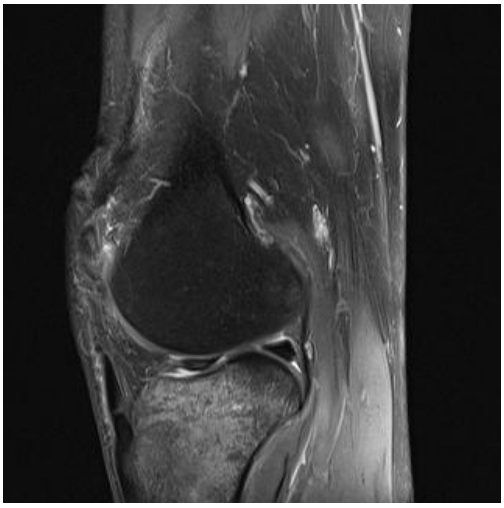
When a piece of a torn meniscus is displaced or can be displaced by a probe during arthroscopy, that piece is termed a “flap.” A horizontal tear will always have a superior flap and an inferior flap, but a vertical extension of the tear can create additional flaps. A radial tear that passes perpendicular to the circumference will not have a flap, but an oblique radial tear results in a free-edge flap, sometimes called a parrot-beak tear because of the curved beak appearance of the flap noted at arthroscopy. The term “parrot-beak tear” should be reserved for arthroscopy reports and not used in the MR description of a meniscal tear pattern.

Displaced Flap Tears

If a meniscal tear results in a fragment displaced away from the site of tear, it is important on knee MRI to identify the fragment location before arthroscopy. It can sometimes be difficult to find the displaced fragment at arthroscopy; if it is not removed, there is often persistent knee pain and locking. A shortened meniscus on coronal or sagittal MR images is often caused by a displaced flap tear but can be seen with radial tears, as discussed earlier; a partially resected meniscus; or a macerated meniscus. When a meniscus is resected, it appears shortened, often with an irregular free edge on MRI. A macerated meniscus is a meniscus in which there is only a small meniscal remnant. Maceration can occur if there is severe cartilage loss and an unstable knee that result in grinding away of the meniscus by the exposed subchondral bone. However, in the absence of prior meniscal surgery, severe overlying cartilage loss, or a radial tear, the most common cause for a shortened meniscus on MRI is a meniscal tear with a displaced fragment. To locate the displaced fragment, one needs to be aware of where these fragments are most commonly found. Approximately two thirds of medial meniscus displaced fragments are found in the posterior aspect of the joint near or behind the PCL, whereas the remaining cases are usually in the superior or inferior recesses above and below the body of the medial meniscus . In contrast to displaced fragments of the medial meniscus, displaced lateral meniscal fragments are seen equally frequently in the recesses of the body of the meniscus and in the posterior aspect of the joint. The posteriorly displaced fragments often extend into the popliteal hiatus.

Bucket-Handle Tear





A bucket-handle tear is a longitudinal tear with central migration of the inner “handle” fragment. This tear pattern occurs seven times more frequently in the MM and has at least five different MR imaging signs: an absent bow tie, a fragment within the intercondylar notch, a double PCL, a double anterior horn or flipped meniscus, and a disproportionally small posterior horn. A bucket-handle tear of the LM can rarely manifest with a double ACL sign, where the fragment is located just posterior to the ACL. Although these signs are sensitive, they are not specific. For example, the absent bow-tie sign, where the innermost bow tie is not present, can also be seen in a small or pediatric patient and with a radial tear of the body, macerated meniscus, or prior partial meniscectomy . Similarly, mimics of the double PCL sign include a prominent ligament of Humphry, a meniscomeniscal ligament, and intercondylar osseous bodies.

Indirect Signs of a Meniscal Tear

Secondary or indirect signs of a meniscal tear are MR imaging findings that can accompany meniscal tears. In technically limited or equivocal cases, these signs can increase the reader’s diagnostic confidence. Although these indirect signs have low sensitivity, they have high specificity and high PPVs for an underlying tear. The most commonly used and better established signs include a parameniscal cyst, meniscal extrusion, and subchondral marrow edema.

Parameniscal Cyst

There are many causes of fluid-filled structures around the knee including cruciate ganglia, synovial cysts, bursitis, and parameniscal cysts. On T2-weighted imaging, a parameniscal cyst is a high-signal-intensity fluid collection either directly overlying a meniscus or adjacent to a meniscus with a fluid track connecting to the periphery of a meniscus . There is a strong association between the presence of a parameniscal cyst and an underlying meniscal tear. The reported association between parameniscal cysts and meniscal tears has ranged from 90% to 100% in MRI series. The only exception to this high association is at the anterior horn of the lateral meniscus where an underlying meniscal tear was found in only 64% of patients with these cysts.

Subchondral Bone Marrow Edema Beneath a Meniscus

The most common cause of a focal subchondral area of high signal intensity on T2-weighted MRI of the knee is reactive edema beneath an area of cartilage degeneration. However, after an episode of acute trauma, a subchondral area of high T2 signal intensity is often cause by acute hemorrhage and is termed a “bone bruise.” Biopsies of bone bruises have identified hemorrhage and trabecular fractures . In one study of 70 patients who underwent knee MRI and arthroscopy, a focus of tibial subchondral edema beneath a meniscus had a 92–100% positive predictive value for an overlying meniscal tear . In another study, a bone bruise in the posterior margin of the medial tibial plateau had a positive predictive value of 64% for the presence of a peripheral posterior horn medial meniscal tear.

Two-Slice-Touch Rule

As an extension of these two studies , investigators first noted in 1993 and confirmed in 2006 and 2009 that if intrameniscal signal contacted the surface of the meniscus on only one MR image, there was only an 18–55% likelihood that a tear of the meniscus would be found at arthroscopy. In contrast, if there was surface contact on two or more images, there was a 90–96% likelihood that a meniscal tear would be identified at that location on subsequent knee arthroscopy. The signal to the surface must be in the same area of the meniscus on the two images, but one image can be in the coronal plane and one, in the sagittal plane. This observation has been referred to as the “two-slice-touch rule”.

Diagnostic Errors

Diagnostic errors can be divided into false negative and false-positive errors. False-negative errors commonly involve the LM, particularly when the tear is small and involves the posterior horn . These errors are either anatomic (tears are mistaken for normal anatomic structures) or technique related (arterial pulsation or magic angle effect that obscures a tear). False-positive errors include mistaking normal anatomic structures and variants for a meniscal tear. Other causes include the magic-angle effect, healed tears, and limitations of arthroscopy. The magic angle effect occurs when collagen fibers are oriented 55° relative to the magnetic field, which is often seen in the upslope medial segment of the LM posterior horn at imaging. This effect commonly occurs within the posterior horn and appears as amorphous increased signal intensity that does not extend to the articular surface, particularly on non–fluid-sensitive PD-weighted MR images. Healed tears can show retained abnormal increased signal intensity for an undefined period. Clinical history, physical examination, and possible arthrography may help differentiate a healed tear from a possible new tear or re-tear.

2. Conclusion

MRI is a highly accurate imaging method for diagnosing meniscal tears. To avoid errors in diagnosing meniscal tears, those interpreting MR examinations of the knee need to be aware of the attachments of the menisci and the normal variations in meniscal anatomy that may resemble a meniscal tear. In addition, by being aware of the patterns of meniscal tears, it is easier to diagnose the less common tears. In my recent experience, a definitive diagnosis of an intact or a torn meniscus can be made in 95% of knee MR examinations. In the remaining 5% of patients, it is not possible to be definitive but a diagnosis of a possible tear or a probable lateral posterior root tear or a differential diagnosis of meniscal fraying or tear should be given.

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