Imaging of meniscal and ligamentous injuries of the knee in children

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Introduction

Knee trauma is a common reason for presentation to the pediatric orthopedic clinic in children and adolescents. In fact, sports related accidents are more frequent than motor vehicle accidents [1-3]. The most frequently encountered injuries in this setting include fractures (contusions, growth plate injuries, osteochondral lesions), lesions of the extensor mechanism, and meniscal tears with or without ligamentous rupture. The Imaging modalities for the diagnosis of meniscal and ligamentous injuries as well as their semiology will be discussed in this chapter.

Imaging modalities

The recommendations of the American College of Radiology (ACR) on the radiographic evaluation of knee trauma based on the mechanism of injury and physical exam underline the necessity for conventional radiographs and MRI in most patients [4]. Other imaging modalities are less commonly indicated.

1. Conventional radiographs

Two orthogonal views are required and are generally sufficient in acute trauma or pain experienced during physical exercise: anteroposterior and true lateral views with the knee in extension. The following findings may be seen on conventional radiographs: 1. Knee joint effusion on lateral radiographs appearing as a thickening of the suprapatellar recess; 2. Traumatic bone or osteochondral lesions; 3. Dysplastic deformities (trochlear dysplasia, patellar dysplasia, etc.). Comparative radiographs are not indicated in this setting and should be avoided.

2. Magnetic resonance imaging (MRI)

Magnetic resonance is the preferred imaging modality for the assessment of intra-articular derangements of the knee in both adults and children. This allows a minute analysis of the meniscal and ligamentous structures, extensor mechanism, cartilage, bone marrow signal, and presence or absence of edema of the adjacent soft tissues. The MRI exam must include views in the 3 planes and in various sequences. As a rule, fat saturation proton density, T1, and eventually echo gradient T2* images must be obtained [5-10]. A standard MRI exam lasts for 20 minutes. With the development of new imaging techniques, three-dimensional reconstructions can be obtained in a shorter period of time with an excellent diagnostic value. However, this setting is not available on all MRI machines [11]. There is no consensus on the optimal moment to order an MRI; too early and post-traumatic edema may overestimate the lesion; Too late and important diagnostic information may be delayed. In addition, the use of an adapted antenna may be impossible in the presence of an immobilization apparatus such as a cast, thereby diminishing the quality of the acquired images. Injection of contrast media such as Gadolinium is usually unnecessary when the traumatic nature of the injury has been established.

Indications for MRI include the suspicion of internal derangements of the knee, the search for an occult fracture, persistent posttraumatic pain, and hemarthrosis.

3. Computed tomographic scan

Computed tomography is usually not indicated except when a detailed analysis of an associated bony lesion is required [4].

4. Ultrasonography

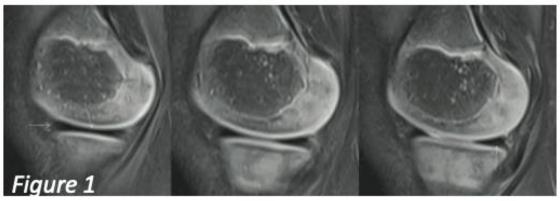
Ultrasonography is a powerful tool for the evaluation of joint effusion, the collateral ligaments, and the tendons of the extensor mechanism. It is also more sensitive than MRI in the evaluation of meniscal injuries [12]. However, ultrasonography is not recommended by the ACR in the diagnostic workup of meniscal and ligamentous injuries of the knee since it does not allow an evaluation of the entirety of neither the menisci nor the cruciate ligaments.

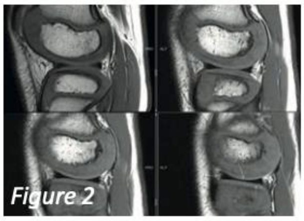
Normal findings

Normal findings on an MRI exam of the knee will be developed in this section.

1. Menisci

The medial meniscus is shaped like a “U” or “open C”, and the lateral meniscus, being more circular, is shaped like an interrupted “O”. Both menisci have a triangular appearance when sectioned with the base at the periphery and a thin central free edge. From front to rear, the meniscus is subdivided into an anterior horn, a body, and a posterior horn [13] (figures 1-3).





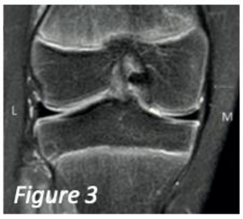


Figure 1*: Contiguous sagittal views using fat saturation proton density MRI of the medial meniscus in a six-year-old child. Horizontal arrow: Anterior horn; oblique arrow: body; vertical arrow: posterior horn.*

Figure 2*: Contiguous sagittal views using T1 MRI of the lateral meniscus in the same patient as figure 1. Horizontal arrow: anterior horn; oblique arrow: body; vertical arrow: posterior horn.*

Figure 3*: Coronal view using fat saturation proton density MRI of the knee in a 12-year-old child showing the body of the meniscus and the medial collateral ligament (arrow). L: lateral, M: Medial.*

The menisci grow in size with age. However, the growth of the lateral meniscus is slower than the corresponding surface of the tibial epiphysis [14]. The body is the narrowest part of the menisci. The structures that ensure the attachment of the menisci are easily recognizable, swhen they exist. These consist of the anterior intermeniscal and meniscofemoral ligaments. On the medial meniscus, the meniscofemoral and meniscotibial liagments are prolongations of the deep fibers of the medial collateral ligament; the capsular attachment of the lateral meniscus is looser, but the fascicles of the meniscopopliteal ligament facing the posterior horn are identifiable.

MRI of the menisci shows a low intensity signal on all sequences owing to their fibrocartilaginous nature. In practice, it is impossible to distinguish the two structural zones of the menisci: the richly vascularized peripheral “red zone” and the central avascular “white zone”. Meniscal signal on MRI, as initially described by Crues et al. in 1987, is classified into four grades: Grade 0 corresponds to a globally homogeneous, low intensity signal of the meniscus; Grade 1 corresponds to a zone with a punctiform or ovoid higher intensity signal, without communication with an articular surface or the meniscocapsular junction; Grade 2 corresponds to linear or arcuate increased signal intensity without communication with the articular surfaces, although it may reach the meniscocapsular junction; Grade 3 is a linear or arcuate intrameniscal increased signal that is rather large and communicates with one or both articular surfaces. Grades 1 and 2 in both children and adults do not signify meniscal tear [5]. In children, increased signal intensity is due to a highly vascularized area and is found in 60% of children younger than 13 years of age; in adults, this is often due to mucoid degeneration of the meniscus. The increased signal intensity is generally localized to the posterior horn of the medial meniscus [15] (figure 4).

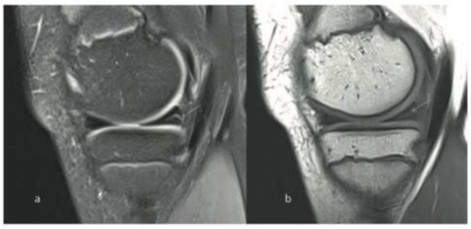


Figure 4*: Sagittal view using fat saturation proton density (a) and T1 (b) MRI of the knee in an 11-year-old child. An area of relative increased signal intensity can be seen at the level of the posterior horn of the medial meniscus (oblique arrows). This aspect is not abnormal.*

The aspects of grades 1 and 2 are classic pitfalls, often falsely interpreted as a meniscal tear [16]. A folded appearance of the free edge of the medial meniscus may be observed on the sagittal view without signifying pathology [16,17].

2. Cruciate ligaments

The anterior cruciate ligament (ACL) is an oblique fibrous band, easily recognizable on sagittal views of the knee, and stretched between the medial intercondylar eminence on the front and bottom, and the posterior part of the medial edge of the lateral femoral condyle on the rear and top (figure 5).

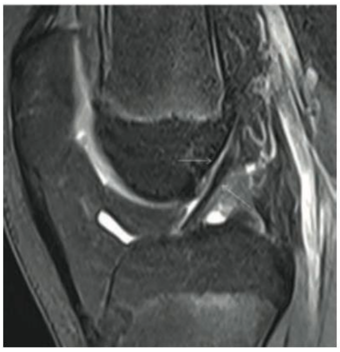


Figure 5*: Sagittal view using fat saturation proton density MRI of the knee in an 11-year-old child illustrating the morphology of the ACL (oblique arrow): linear, and with a sharp anterior edge that is virtually parallel to the Blumensaat line (horizontal arrow).*

When the knee is in extension, the ACL is linear and forms an angle of 10° or less with the Blumensaat line (roof of the intercondylar notch), with a low signal intensity on all sequences, and a relatively striated aspect. On coronal views, the constitutive bundles (anteromedial and posterolateral) are discernable. Recognizing the ACL in the coronal, sagittal and axial planes is essential in order to detect partial tears [18-20]. The posterior cruciate ligament (PCL) is longer but thicker than the ACL, extends from the posterior, median part of the tibial epiphysis on the bottom and rear, to the anterior, intercondylar edge of the medial condyle; In extension, the PCL forms a concave curve on the bottom and front (figure 6).

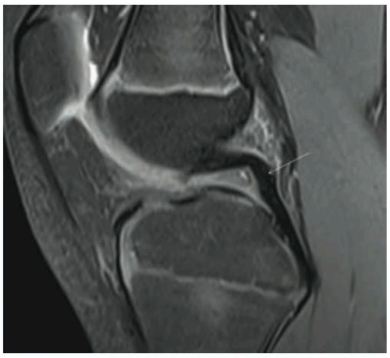


***Figure 6**: Sagittal view using fat saturation proton density MRI of the knee of the same patient as in figure 5. The morphology of the LCP (oblique arrow) can be seen with its anteroinferior concavity and its characteristic thickness.*

3. Other ligaments

The collateral ligaments are easily identifiable on MRI and on ultrasound. The proximal, femoral insertions of the collateral ligaments are entirely epiphyseal [21]. A significantly lower intensity is seen on MRI with sharp and regular contours (figure 3). The anterolateral ligament is difficult to visualize in children younger than 15 years old [22].

Meniscal injury

The prevalence of meniscal injuries is lower in children compared to adults.

1. Meniscal tears

Meniscal tears may be isolated or associated with ligamentous and/or osteochondral lesions. In the context of trauma, the medial meniscus is more often damaged than the lateral meniscus, and its posterior horn more often injured than the anterior horn or body. The strong correlations between the aspect of the meniscus on MRI and surgery has long been established, with a sensibility of 85% and a specificity of 88 to 100% [7,8].

Different types of meniscal tears exist. However, only signal intensity alterations that communicate with the articular surface are considered pathological (grade 3). Meniscal tears may be horizontal, vertical, radial or oblique, peripheral or central, or of the bucket handle type. Bucket handle tears are distinct entities, and the diagnosis is easily made when a large fragment is projected within the intercondylar notch, giving rise to a “double PCL” sign on the sagittal views, and an absence or marked alteration of one of the meniscal horns or the body (figure 7). A meniscal flap may be projected anteriorly and give the aspect of a “double anterior horn”. A separation between the capsule and the meniscus or a loose meniscal fragment may be difficult to identify in children [5,23]. Finally, tears of the posterior horn of the lateral meniscus may be underestimated [24].

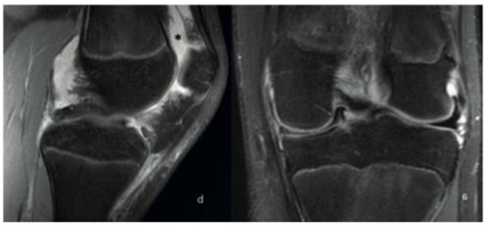


Figure 7*: Coronal (a) and sagittal views (b) using fat saturation proton density MRI of the knee in a 13-year-old adolescent illustrating a bucket handle tear of the medial meniscus. The loose fragment (oblique arrows) is situated in the intercondylar notch on the coronal view (a) and gives the appearance of a “double PCL” on sagittal views (b). *: hemarthrosis.*

2. Discoid meniscus

A discoid deformity of the meniscus constitutes anomalies in both the shape and attachment of the meniscus. Discoid menisci are frequently encountered and affect the lateral meniscus (1.5% to 15% of the population depending on the series) more frequently than the medial meniscus (0.3% of the population) and are bilateral in almost 1/3 of cases. Multiple anatomical classifications have been developed [5,25-32]. The etiology remains unknown. A discoid meniscus may be asymptomatic but predisposes to complications which may be manifested clinically (pain, blocking). A clear history of trauma or intense physical exercise that may have started at an earlier age compared to other types of meniscal tears is often absent. On anteroposterior radiographs, lateral tibiofemoral joint widening, largening of the lateral femoral condyle with a squared shape, and cupping of the lateral tibial plateau may be seen. On MRI, the diagnosis is easily made in the absence of meniscal avulsion. The discoid meniscus is generally larger and thicker than regular menisci, and the anterior and posterior horns are seen on three contiguous sagittal slices [25]. A relatively thick horizontal fissure is consistently found (figure 8). If completely displaced, the discoid nature of the meniscus may be difficult to confirm [33] (figure 9).

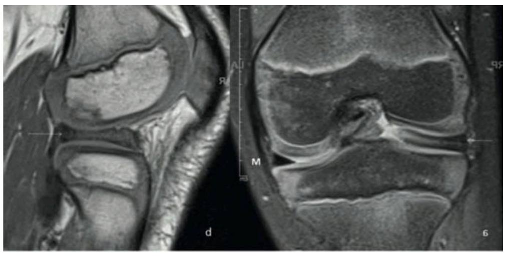


Figure 8*: Coronal view using fat saturation proton density (a) and sagittal view using T1 (b) MRI of the knee in a 7-year-old child. A discoid lateral meniscus is seen (horizontal arrow). M: medial.*

***Figure 9**: Coronal (a) and sagittal (b) views using fat saturation proton density MRI of the knee in a 12-year-old adolescent illustrating a lateral meniscal tear over a discoid meniscus with a centrally and posteriorly displaced fragment (arrows). M: medial.*

3. Meniscal cyst

Rarely found in children and adolescents, a meniscal or parameniscal cyst presents as painful and renitent swelling over the femorotibial joint line. Ultrasonography is non-specific since the lesions may have a finely echoic, or even heterogenic content. On MRI, a meniscal tear, most often longitudinal, is consistently found; In the absence of such a tear, the differential diagnosis of a soft tissue mass should be considered [6,34].

Ligamentous lesions

1. Anterior cruciate ligament lesions

The preferred imaging modality for the assessment of the ACL is MRI. Both the direct and indirect signs that are described in adults may be applied to children as well [18,35]. Direct signs of an ACL tear include discontinuity of the fibers, modification of their orientation, and an abnormal signal (difficult to assess when there is significant joint effusion). Indirect signs include verticalization of the PCL, anterior shift of the tibia, posterior translation of the posterior horn of the lateral meniscus, joint effusion, and bone contusions (lateral femoral condyle and medial tibial plateau) (figure 10).

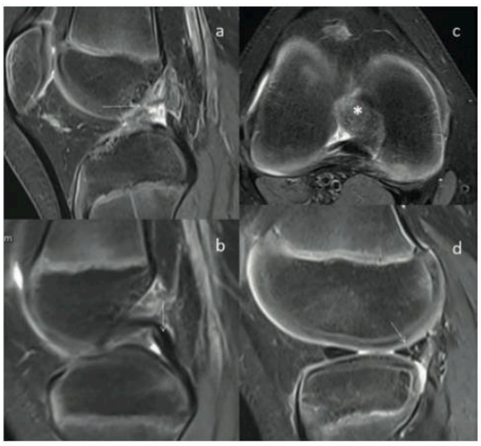


***Figure 10**: Sagittal (a,b,d) and transverse views (c) using fat saturation proton density MRI of the knee in an 11-year-old child illustrating a complete ACL tear (a, horizontal arrow; c, asterisk) with marked angulation of the PCL (b, vertical arrow), and vertical tear in the posterior horn of the lateral meniscus (d, oblique arrow).*

These signs are rarely observed in their totality. One study found a sensitivity of 95% and a specificity of 88% in diagnosing ACL tears using MRI [35]. The diagnosis of a partial ACL tear is difficult to make and, based on the findings during the physical exam, the MRI may be repeated.

Tibial eminence fractures are more commonly encountered in children than purely ligamentous injuries and correspond to an osseocartilaginous avulsion of the distal insertion of the ACL. Multiple subtypes of tibial eminence fractures exist and are classified according the Meyers and McKeever classification, which was later modified by Zaricznyj (36). The classification is based on a sagittal radiograph of the knee but may also be applied to MRI or CT-scan. Type I corresponds to no or minimal displacement, type II (the most frequent) corresponds to an anterior displacement of the fragment with an intact posterior hinge, type III is characterized by complete displacement of the osteochondral fragment, and type IV corresponds to complete displacement with rotation and comminution (figure 11). As a general rule, in avulsion fractures of the intercondylar eminence, the ACL is normal. Postoperative MRI evaluation after surgical repair of the ACL will not be discussed in this chapter.

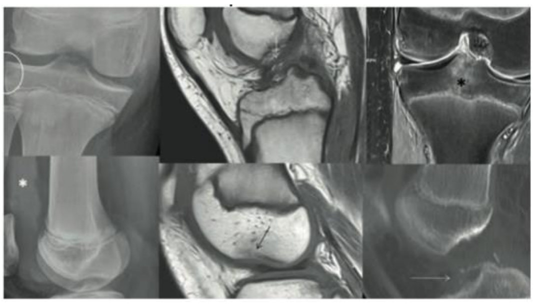


Figure 11*: 13-year-old adolescent presenting with trauma to the right knee. The initial radiographs (a,b) show a bony avulsion of the lateral border of the tibial epiphysis signaling a Segond fracture (a, circle), abundant hemarthrosis (b, asterisk), and a marked lateral condylar notch (b). MRI three weeks after the incident (c,d : sagittal views using T1 images; e: coronal view using fat saturation proton density images) show a continuous but serpentine aspect of the ACL (c, vertical arrow), impaction of the lateral condyle (d, arrow), and edema at the level of the tibial eminence (e, asterisk). CT-scan obtained at the same time as the MRI (f) shows a comminuted fracture of the intercondylar eminence (f, horizontal arrow).*

2. Other ligamentous injuries

Injuries to the PCL are rare in children and adolescents and are generally secondary to hyperextension of the knee. A PCL rupture is diagnosed using MRI and shows an interruption of the fibers and/or a global or focal increased signal of the ligament. It is rarely an isolated injury. A mechanism of injury similar to that of ACL injuries may lead to an avulsion of the tibial insertion of the PCL (figure 12).

***Figure 12**: Sagittal views using T1 (a) and fat saturation proton density (b) MRI of the knee in a 13-year-old adolescent who had presented 3 months prior with trauma to the knee with persisting pain and instability. An osteochondral avulsion fracture of the posterior insertion of the PCL (oblique arrows) can be seen.*

Injury to the collateral ligaments is rarely isolated, and medial compartment injuries are much more frequently observed than at the lateral compartment. These injuries may be assessed using ultrasound or MRI. On MRI, collateral ligament injuries are classified into three grades: grade 1, edema of the ligament and adjacent soft tissues with normal appearance; grade 2, partial disruption with thickening and edema of the ligament; grade 3, complete disruption of the ligament. In these lesions also, an osseocartilaginous avulsion fracture that is generally located at the proximal insertion may be secondary to the same mechanism of injury (figure 13).

***Figure 13**: 11-year-old child presenting with trauma to the right knee. The initial radiograph (a) shows an avulsion fracture of the lateral edge of the femoral epiphysis (a, oblique arrow). MRI obtained on the same day (b: sagittal view using T1 images; C: transverse view using fat saturation proton density images) confirms the avulsion fracture (oblique arrow) at the proximal insertion of the lateral collateral ligament (b, horizontal arrow) and the popliteus tendon.*

Associated lesions

Clinical and radiographic signs of hemarthrosis of the knee is an indication for an MRI. In fact, significant injuries (lesions of the extensor mechanism, osteochondral lesions, meniscoligamentous lesions, occult fractures) are observed in almost 50% of cases, with meniscoligamentous injuries found in almost 25% of cases [37-39]. Meniscal and ligamentous injuries may be isolated or associated with numerous other lesions, especially of the medial meniscus, ACL, and medial collateral ligament [20,40,41].

Findings of bone edema may provide some insight into the mechanism of injury and potential associated meniscoligamentous lesions must be ruled out [42]. Contrary to adults, traumatic bone contusion in children may be isolated without associated meniscoligamentous lesions [41,43,44]. On conventional radiographs, the careful search for an osseous injury is imperative: e.g. in a Segond fracture, avulsion of the lateral edge of the lateral tibial plateau may be discrete and may even be absent on MRI; Its discovery must lead to an assessment of the ACL in order to rule out rupture, tibial eminence fracture and/or a lateral meniscal tear (figure 11).

Messages

• MRI is the imaging modality of choice in meniscoligamentous injuries in children and adolescents as a complement to physical exam and conventional radiographs.

• In acute injuries, there is no consensus on the optimal moment for the realization of an MRI.

• Meniscal lesions may be isolated or, more frequently, associated with other injuries.

• An isolated hemarthrosis is an absolute indication for an MRI.

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