Knee MRI in the pediatric population

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Learning objectives

- To describe and illustrate the MRI findings commonly present in the evaluation of knee injury in pediatric patients. A special emphasis is given to the skeletally immature knee.

Background

The knee is the joint most commonly imaged with MRI in the pediatric population. While older adolescents are more likely to have pathology similar to adults; prior to skeletal maturity, the presence of the growth plates and the composition of bone may produce patterns of injury unique to children.

The advantages of MRI include absence of ionizing radiation and ability to image the soft tissues and to demonstrate pathologic conditions of bone that are undetectable at plain radiography. The multiplanar imaging also allow pathologic processes to be displayed in the optimal projection.

MRI PROTOCOL

1. The knee should be imaged in three orthogonal planes (axial, sagittal, and coronal), and at least one sequence should be obtained with fat saturation and one without.
2. A dedicated extremity coil should be used to improve signal-to-noise ratio.
3. Images are obtained at a 3-mm slice thickness with a 1-mm interslice gap.
4. Standard imaging sequences often include axial proton-density-weighted fat-suppressed imaging, coronal T1-weighted imaging, coronal proton density-weighted or T2-weighted fat-suppressed imaging, and sagittal proton-density-weighted or T2-weighted fat-suppressed imaging.

Imaging findings OR Procedure details

Procedure Details: Data collection was performed retrospectively (using the PACS system) in patients under 18 who were referred for MRI assessment of the knee joint at our hospital. The most representative cases of each pathology were selected for this presentation.
1) Physeal Fractures

- Prior to skeletal maturity, the physis is the "weakest link" and ligaments have a normal physiologic laxity. For these reasons physeal fractures are more common than ligamentous injury.

- Most physeal fractures are clinically evident and obvious on radiography; however, physeal fractures of the knee, particularly the distal femur, can occasionally be very subtle or frankly occult on radiography.

- Salter II fractures of the distal femur are the most common physeal fracture diagnosed by MR at the knee.

- On MRI the fractured line is seen as high signal on fat saturated T2 or proton density images and the fractured portion of physis is widened.

- Stress or overuse injuries to the growth plates of the distal femur and proximal tibia may produce knee pain. Physeal widening occurs due to cartilaginous ingrowth into the metaphysis. There is adjacent bone marrow edema. These areas of physeal widening are thought to be secondary to repetitive stress and differ from Salter-Harris type I fractures, which result from acute injury. With this type of chronic injury, a fracture line is not identified and the widening can be focal.
2) Avulsion Fractures

Tibial spine avulsion fractures are common prior to physeal closure. In most cases, the ACL is intact but tibial spine avulsions may occur in association with ACL tears.

3) Osteochondral Injuries

- One study showed that chondral injuries were the most common lesions in children examined on MRI for evaluation of internal derangement of the knee. Chondral lesions were significantly more prevalent than meniscal or ligamentous injuries in skeletally immature patients and were almost as prevalent in the skeletally mature.

Classification of osteochondral injuries
Grade 1: thickening of the cartilage with abnormal signal.

Grade 2: superficial ulceration or fissuring of the cartilage.

Grade 3: deep ulceration or fissuring of the cartilage.

Grade 4: full-thickness chondral injury with bruising of subchondral bone.

Grade 5: osteochondral injury with separation of osteochondral fragment.

- Children with patellar instability (e.g. patella alta, throbclear dysplasia, transient patella dislocation) are prone to chondral injuries in the patellofemoral joint.

(see Extensor Mechanism below for image examples)

3) Osteochondritis Dissecans (OCD)

- OCD is a common source of knee pain and dysfunction in children. OCD most commonly involves, in order of decreasing frequency, the medial femoral condyle, the lateral femoral condyle, the femoral trochlea, and the patella.

- The exact etiology of OCD is presently unknown. Repetitive microtrauma is thought to be the primary mechanism responsible for the development of OCD. However, other causes, including acute trauma, ischemia, ossification abnormalities, and genetic factors, have also been proposed.

- OCD may be diagnosed with radiography and seen as a focal lucency involving subchondral bone, often containing a central osseous fragment and variable degrees of surrounding sclerosis. However, MRI is useful in assessing stability of the lesion, which has surgical implications because loose or displaced fragments require surgical management.

MRI signs of instability: presence of a high-signal-intensity line along the fragment interface; disruption of the subchondral bone plate; high T2 signal intensity cartilage fracture line; fluid-filled osteochondral defect; multiples cysts or single cyst greater than 5-mm in diameter adjacent to the lesion.
Fig. 2

References: Radiology, Hospital de São João - Porto/PT
EXTENSOR MECHANISM

- Cause of anterior knee pain

1) Patellar Instability

- There are many factors that predispose to patellar instability including patella alta, trochlear dysplasia, genu valgum, ligamentous laxity and abnormal morphology of the patellar facets.
- In this setting osteochondral injury of the patellofemoral joint and acute patellar dislocation can occur.
Figure – 14 year-old-boy with trochlear dysplasia. Axial fast spin-echo proton density-weighted image (a) at the level of trochlear cartilage shows a flat, horizontally oriented trochlear joint surface with a shallow sulcus. More cranially (image b) patellar cartilage ulceration (arrowhead) is seen as a consequence of trochlear dysplasia.

Fig. 4

References: Radiology, Hospital de São João - Porto/PT
Acute patellar dislocation is most often seen in patients aged 13-20 years and is more common in girls. The most common injury mechanism is an internally rotating twisting force applied to a flexed knee while the foot is planted.

Approximately 50%-75% of patellar dislocations are occult in that they have self-relocated at the time of physical examination or imaging.

MR imaging signs of dislocation and injury to the soft tissues and ligaments of the knee, and osteochondral fractures must be excluded, especially in the setting of hemarthrosis.

Pathognomonic MRI sign for recent patellar dislocation is the classic finding of bone marrow contusions at the medial patellar facet and the anterolateral femoral condyle (kissing contusions), which appear as low marrow signal intensity on T1-weighted images and increased marrow signal intensity on T2-weighted images. Other findings include
sprain or tear of the medial retinaculum, strain or tear of the vastus medialis obliquus, and joint effusion.

Fig. 6

References: Radiology, Hospital de São João - Porto/PT

2) Osgood-Schlatter Syndrome and Tibial Tubercle Avulsion

Fractures

- Chronic avulsion or overuse injuries can involve the tibial tubercle, termed "Osgood-Schlatter disease." The tibial tubercle is an anterior extension of the tibial physis and is prone to injury because of its unique composition, which varies from other physes. As the tibial tubercle matures, its susceptibility to injury from stresses incurred by the patellar tendon increases.
• Repetitive stress on the tibial tubercle by the patellar tendon causes inflammation at the patellar tendon insertion site, reactive bone formation, bone marrow edema, proximal patellar tendon thickening, and soft tissue swelling.

• Although Osgood-Schlatter disease is a clinical diagnosis, MRI is useful in characterizing these changes, especially in the early stage of disease when only bone marrow edema may be present adjacent to the tibial tuberosity.

• Osgood-Schlatter disease may predispose to avulsion fractures of the tibial tubercle, which also may be seen as an acute injury, most commonly in teenage boys involved in jumping sports.

• When osseous irregularity is seen at this site in the absence of other findings and symptoms, irregularity of the ossification center must be considered as a normal variant.

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Fig. 7

References: Radiology, Hospital de São João - Porto/PT
3) Sinding-Larsen-Johansson Syndrome and Patellar Sleeve Fractures

- Acute avulsion of the cartilage of the inferior patellar pole with an underlying bone fragment is termed "patellar sleeve fracture" and occurs most commonly in the 8- to 12-year old population.

- Although radiographic and MR findings are similar and include joint effusion, avulsed osseous fragment, and patella alta, MRI can identify the true extent of injury, including the presence of a nondisplaced osteochondral fracture, the extent of soft-tissue injury, and the need for operative management.

- Chronic avulsion injury of the inferior patellar pole is termed "Sinding-Larsen-Johansson syndrome." MRI is also useful to determine the extent of findings, including fragmentation of the inferior patellar pole, infiltration of Hoffa fat-pad, and thickening of the proximal patellar tendon. Calcification or ossification of the tendon can also be identified.

Fig. 8

References: Radiology, Hospital de São João - Porto/PT
MENISCI

- Meniscal injury is uncommon prior to physeal fusion, but becomes very common in older teens after physeal fusion.

- The medial and the lateral menisci should have two contiguous images of the body of the meniscus if 4- or 5-mm-thick slices are obtained, on sagittal plane. However, this sign may not be as reliable in the pediatric population because the size of the meniscus will vary with age, and the "bowtie sign" is described in the adult meniscus, which is approximately 9-12 mm in width.

Meniscal degeneration and tears

Grade 1 refers to the uniformly low normal meniscal signal, grade 2 describes increased signal within the meniscus that does not extend to an articular surface, and grade 3 refers to abnormal signal extending to an articular surface indicative of a tear.

There are multiple types of meniscal tears, including horizontal, vertical, bucket-handle, radial, peripheral, and displaced flap tears.
Discoid Menisci

Most meniscal injuries in children under 10 years of age are due to discoid menisci. Discoid menisci are almost always lateral and may also present with tears or locking symptoms in adolescence. When there is isolated injury to the lateral meniscus, a discoid meniscus should be suspected.

On MRI, a discoid meniscus extends too far medial towards the tibial spines (greater than 13 mm transverse or 2 mm greater than the medial meniscus).

On sagittal images, continuity of the anterior and posterior horns on three or more 4- or 5-mm thick images suggests a discoid meniscus.
Wrisberg-type discoid menisci lack normal attachments and may displace. When a discoid meniscus is torn and/or displaced it may be difficult to identify as discoid.

**Fig. 10**

*References:* Radiology, Hospital de São João - Porto/PT

**LIGAMENTS**

- Children have normal physiologic laxity of ligaments, consequently, ligament injuries are relative uncommon prior to skeletal maturity. After the growth plates fuse at the time of puberty, ligamentous injuries become more common. With increasing participation in competitive sports at all ages, ligamentous injuries are now more common in the skeletally immature knee and very common in adolescents with fused physes.

The most common ligamentous injury at the knee is the tear of the anterior cruciate ligament (ACL).
MRI Findings in ACL Tear:

As in adults, the disrupted ACL will show increased signal, disruption and ill-definition. A pattern of bone marrow edema in the lateral femoral condyle and posterolateral tibial plateau is commonly seen.

Other secondary signs that are often seen are: joint effusion, deep lateral condylar sulcus sign, anterior tibial translation with uncovering of posterior horn of lateral meniscus and Segond fracture.

ACL injuries are commonly associated with injuries to the collateral ligaments and menisci.

Fig. 11
References: Radiology, Hospital de São João - Porto/PT
• **Posterior cruciate ligament (PCL) injuries** are uncommon in the pediatric population, but may occur with hyperextension injuries or with severe multiligamentous injury from knee dislocation.

• **Isolated collateral ligament injuries** are not infrequent; however, complete tear of a collateral ligament in absence of an ACL or PCL injury is rare.

**JOINT EFFUSION**

The presence of a joint effusion is a nonspecific sign. Most injuries causing ligamentous or meniscal injury are accompanied by an effusion. Lipid material layering within a knee joint effusion is indicative of an underlying fracture.

**Popliteal cysts** (Baker cysts) may develop in young children without underlying abnormality, as opposed to adults.

A variety of nontraumatic processes may also cause knee joint effusions including septic arthritis, juvenile idiopathic arthritis, hemophilia, synovial venous malformation, and pigmented villonodular synovitis.

**INCIDENTAL FINDINGS**

• **Avulsive cortical irregularity** or "cortical desmoids" represent a normal finding seen at the posteromedial aspect of the distal femoral metaphysis. This may produce a scalloped appearance to the external cortex. Findings are usually symmetric or at least similar bilaterally. These lesions have high signal on T2-WI and a surrounding low signal rim may be present.

• **Fibrous cortical defects** (<2 cm) and the histologically identical but larger non-ossifying fibromas (>2 cm) are fibroxanthomatous lesions that occur in approximately 20-30% of children. Fibrous cortical defects will therefore be a common incidental finding on knee MRI in children. The appearance of the lesion will vary depending on its stage of development. The lesions are well defined, unilocular or lobulated, cortical in location and without associated edema. Newer lesions will show high signal on fat-saturated proton density imaging, whereas older, involuting lesions will show low signal.
Fig. 12

*References*: Radiology, Hospital de São João - Porto/PT

- **Osteochondroma** is another common benign lesion that is common in metaphyses at the knee. They may be pedunculated or sessile. MRI confirms the contiguity of the osteochondroma with the underlying bone and will nicely show the cartilaginous cap on fat saturation proton density images.

**NOW... TEST YOUR KNOWLEDGE WITH A COMPLEX CASE!**
TEST YOUR KNOWLEDGE!

- Clinical Details: 13 years-old-girl, obese, knee luxation after jump

Coronal fast spin-echo proton density-weighted sequence

Fig. 13

References: Radiology, Hospital de São João - Porto/PT
TEST YOUR KNOWLEDGE!

- Clinical Details: 13 years-old-girl, obese, knee luxation after jump

Sagittal fast spin-echo proton density-weighted sequence

(see answers on next slide ...)

Fig. 14

References: Radiology, Hospital de São João - Porto/PT

Click here to see the answers Fig. 15 on page 34

Images for this section:
Figure – 13-year-old girl with left knee pain after a fall. The plain film (a) does not show any abnormality. An MRI was performed and a fracture passing through the epiphysis, physis and metaphysis (Salter-Harris type 4) is seen has a low signal intensity line on coronal T1-WI (b) and has a high signal intensity line on coronal T2*-weighted gradient-echo image (c) (green arrows). Also the lateral femoral condyle has an area of low signal intensity on T1-WI (b) and high signal intensity on T2*-weighted gradient echo image (c) representing a bone contusion (white curved arrows).
BONE AND CARTILAGE
Osteochondritis Dissecans (OCD)

Figure – 17-year-old boy with left knee pain in the medial compartment without history of trauma. Conventional radiography of the left knee in the AP view is normal (image a) but in Merchant view (image b) a subchondral lucency is seen in the medial femoral condyle (arrow). In this location, this finding is highly suggestive of OCD.

Fig. 2
Figure – Same patient as in figure x. OCD lesion is surrounded by inner rim of high T2 signal intensity (arrow). Low signal intensity subchondral bone is disrupted at inferior edge of the OCD lesion (arrowhead). These findings are suggestive of an unstable lesion.
Figure – 14 year-old-boy with trochlear dysplasia. Axial fast spin-echo proton density-weighted image (a) at the level of trochlear cartilage shows a flat, horizontally oriented trochlear joint surface with a shallow sulcus. More cranially (image b) patellar cartilage ulceration (arrowhead) is seen as a consequence of trochlear dysplasia.
Figure – 13 year-old-girl with anterior knee pain. Sagittal fast spin-echo proton density-weighted image (a) shows a high riding patella with a patellar height ratio (PHR) of 1.5. The length of the patellar tendon (line A) is measured posteriorly from the patellar apex to its attachment to the tibial tuberosity and is divided by the longest superoinferior diameter of the patella (line B) to obtain the PHR, as follows: PHR = A/B. A patellar height ratio of more than 1.3 indicates a high-riding patella (patella alta). Axial fast spin-echo proton density-weighted image b) at the level of femoropatellar joint shows deep ulceration of patellar cartilage with associated subchondral bone erosion (arrowhead) and bone marrow edema (*)
Figure — 17-year-old girl with anterior knee pain. Axial (a) and coronal (b) fast spin-echo proton density-weighted image show detachment of the medial patellofemoral at patellar insertion (green arrow). Image (c) was acquired more caudally than image (a) and shows patellar impaction deformity and marrow edema of the intermedial patellar border (green arrow) with associated small bone fragments (arrow head) and marrow edema of the femoral lateral condyle (white arrow). The trochlea is dysplastic. These findings are consistent with transient patellar dislocation.
Figure – 17-year-old boy with knee pain. Sagittal T1-WI (a) and T2-WI with fat saturation (b) shows fragmentation of the tibial tubercle (green arrow) with overlying thickening of the distal patellar tendon and small amount of fluid in the Hoffa fat pad (white arrow). This findings are compatible with Osgood-Schlatter disease.
PATELLA AND PATELLAR TENDON
Sinding-Larsen-Johansson syndrome

Figure – Sagittal proton density-weighted image with fat saturation through knee of 11-year-old basketball player with long standing pain at the level of Hoffa fat pad. The image shows fragmentation of inferior patellar pole with associated bone marrow edema (green arrow). Findings are compatible with chronic avulsion injury of the inferior patellar pole (Sinding-Larsen-Johansson syndrome).

Fig. 8
Figure – 14-year-old girl who twisted her knee. Coronal fast spin-echo proton density weighted image (a) and sagittal T2*-weighted gradient-echo image (b) shows abnormal intrameniscal signal (high signal intensity), in the posterior horn of the lateral meniscus, that communicates with the articular surface representing a horizontal tear (arrows).
Fig. 10

Figure – 7-year-old boy with knee pain and no history of trauma. Coronal fast spin-echo proton density weighted image (a) and sagittal T2*-weighted gradient-echo image (b) shows discoid lateral meniscus with abnormal intrameniscal signal (arrows), compatible with degeneration.
LIGAMENTS
Anterior Cruciate Ligament (ACL) Injury

Figure – 16-year-old boy who injured his knee after playing football. Sagittal fast spin-echo proton density-weighted image (a) shows complete midsubstance tear with both abnormal course and increased signal intensity of ACL (arrow). Coronal fast spin-echo echo proton density-weighted image (b) shows bone marrow contusion as high signal in the bone marrow of lateral femoral condyle. Sagittal conventional spin-echo proton density-weighted image (c) shows uncovering of posterior horn of lateral meniscus (vertical line) and a fracture line at the level of lateral condylar sulcus (arrow).

Fig. 11
NORMAL FINDINGS
NON- OSSIFYING FIBROMA

Figure – 16-year-old boy. The plain film (a) shows a cortically based bone lucency with a thin sclerotic rim and multioculated in appearance (arrow). Coronal fast spin-echo proton density-weighted image (b) shows that the lesion has high and low signal intensity areas (the latter corresponding to ossifying areas), with a peripheral low signal rim corresponding to the sclerotic border.
TEST YOUR KNOWLEDGE!

- Clinical Details: 13 years-old-girl, obese, knee luxation after jump

Coronal fast spin-echo proton density-weighted sequence

(Continue...)
TEST YOUR KNOWLEDGE!

- Clinical Details: 13 years-old girl, obese, knee luxation after jump

Sagittal fast spin-echo proton density-weighted sequence

(see answers on next slide ...)
1. Salter Harris type III fracture (through the physis and epiphysis) in the proximal fibula (white circle in image a), with associated bone marrow edema.

2. Bone avulsion fracture at the insertion of lateral collateral ligament in the lateral femoral condyle (white circle in image b) and grade 2 tear of LCL (arrow in image a).

3. Abnormal course and increased signal intensity of ACL (arrowheads) and PCL (arrow), representing complete tears of both ligaments (image c and d).

4. Bone contusion in the medial femoral condyle and in the tibial spine is also seen (•) in image b and c.

5. Effusion in the supra-patellar bursa (+) – image c and d.
Conclusion

Take-Home Points

• Physeal fractures are commonly identified in plain films but can sometimes be occult. When evaluating a knee MRI always look for fracture lines and physeal widening.

• Before physeal closure, avulsion bone fractures can occur without ligament injury.

• MRI is useful in the context of Osteochondritis Dissecans because it can determine if the lesion is stable or unstable (the later requires surgical management and has a worst prognosis).

• Patellar instability is a common cause of anterior knee pain - identify possible causes (trochlear dysplasia, patella alta); indirect signs of transient patellar dislocation; and osteochondral injuries.

• Acute or chronic avulsion fractures that involve the inferior patellar pole or the tibial tubercle occur exclusively in pediatric patients and MRI can determine the extent of findings in the bone and in the soft tissues.

• Discoid meniscus (variant of the lateral meniscus) is an important cause of meniscal degeneration and tears before age 10.

• Older adolescents with skeletal maturity are more prone to have "adult knee injuries", i.e., ligament and meniscal injuries.

• When evaluating a knee MRI, incidental findings like cortical desmoids or fibrous cortical defects can be present and they shouldn’t scare you!

References

2. Pai, DR; Strouse; PJ. MRI of the pediatric knee. MRI of the pediatric knee. AJR 2011; 196:1019-1027

Personal Information