The paediatric knee: MRI injury patterns and their management

Poster No.: P-0092
Congress: ESPR 2017
Type: Educational Poster
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Keywords: Musculoskeletal, Pediatric, Musculoskeletal joint, Musculoskeletal bone, MR, Diagnostic procedure, Trauma
DOI: 10.1594/espr2017/P-0092

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Learning objectives

- Describe a standard MRI protocol for imaging the paediatric knee.

- Outline the common types and patterns of injury within the paediatric knee with images and surgical correlation where available.

To include:

- Osteochondritis dissecans including criteria for determining stability
- Traction apophysitis including Osgood-Schlatter disease and Sinding-Larsen-Johansson syndrome
- Tibial spine and other avulsion injuries
- Meniscal injury including those associated with a discoid meniscus
- Patella dislocation, subluxation and maltracking
- Patterns of bone marrow oedema associated with common direct and indirect injuries

- Described pitfalls and common incidental findings on imaging the paediatric knee

Background and purpose

The knee is the most commonly imaged joint in children and with an increasing number of children participating in competitive sports, an understanding of the spectrum of abnormalities is essential for a paediatric radiologist.

The aim of this exhibit is to demonstrate both common and uncommon knee injury patterns in children categorised into acute and chronic; a significant amount of which are unique to the developing skeletally immature paediatric population.

Content, imaging findings or procedure details

Technique

Fast sequences and efficient protocols are crucial for imaging children.

- Axial turbo spin-echo T2-W or Proton density (PD) with fat saturation
• Sagittal or Coronal spin-echo T1-W
• Sagittal turbo T2-W or PD-weighted with fat saturation
• Coronal turbo spin-echo PD-weighted and/or T2-W with fat saturation

With rapid advances and wider availability of high-field strength magnets, more children are being imaged with 3-Tesla, which if optimised can shorten the overall examination time and increase resolution\(^\text{14}\).

**Osteochondritis dissecans** Fig. 1 on page 7

Osteochondritis dissecans is defined as a focal idiopathic alteration of subchondral bone with a risk for instability and disruption of adjacent articular cartilage. This has the potential to result in premature arthritis.

Osteochondritis dissecans results from chronic repetitive injury and in children often heals spontaneously.

The commonest site affected (70\%) is the posterolateral aspect of the medial femoral condyle. Less common areas include the lateral femoral condyle, trochlear fossa and patella\(^1\).

As children with osteochondritis dissecans have a better chance of spontaneous healing than adults, the lesion is more often considered stable and the criteria for instability are more cautious:

- Presence of multiple junctional cysts or a single cyst larger than 5mm
- Fluid signal cleft between parent site and fragment
- Overlying cartilage deficiency or multiple marginal discontinuities
- Displaced intra-articular fragments

**Pitfalls:**

Should be differentiated from normal condylar fragmentation and secondary ossification centres, usually found along the far posterior non-weight bearing portion of the femoral condyles

**Traction Apophysitis** Fig. 2 on page 8
Traction Apophysitis occurs when the attachment of tendon to bone is repetitavely strained\textsuperscript{3}.

Osgood Schlatter disease is a relatively common chronic traction injury at the patella tendon insertion onto the tibial tuberosity. Its equivalent at the proximal attachment of the patellar tendon on the inferior pole of patella is Sinding-Larsen-Johannson. Both diseases are thought to be caused by multiple, small avulsion injuries, often posing a diagnostic challenge in cases of acute on chronic injury.

In longstanding cases diagnosis is usually made clinically with radiographic confirmation. However when diagnosis is unclear or there has been an acute event, MRI may aid diagnosis and assess the integrity of the tendon and osteochondral junction.

Radiographic findings include small avulsed osseous fragments, blunting of the infrapatellar fat pad and thickening/poor definition of the tendon. MRI demonstrates oedema within the tendon and infrapatellar fat pad\textsuperscript{16}. The inferior patella or tibial tuberosity may be enlarged with small avulsed osseous fragments.

**Avulsion injuries including tibial spine and patellar periosteal sleeve Fig. 3 on page 9**

An avulsion fracture typically results from an acute tensile force on a ligament or tendon. This force is greater than the capacity of the bony attachment. Children are more prone to avulsion injuries as they have a relative weakness at the osteocartilaginous junction. Commonly affected areas around the knee in children include the cruciate ligaments, collateral ligaments, extensor mechanism and retinacula.

Tibial intercondylar eminence avulsion fractures occur in relation to the distal ACL attachment. They typically occur in boys aged 8-14, and almost always precede physeal closure. They have been classified into 3 types by Meyers and McKeever depending on the degree of fragment displacement.

Intrinsic ACL injuries are commonly mid-substance tears affecting female athletes approaching skeletal maturity; typically they occur post physeal closure however there has been suggestion of a rise of such injuries recently due to increased athletic and competitive sports amongst young adolescents (fig 3c and d).
Avulsion fractures related to the popliteus tendon can occur in isolation to ACL injury and can also be associated with fibular collateral ligament injury (a more severe injury).

Patellar sleeve fractures typically occur at the inferior pole of the patella and involve a sleeve of unossified patellar cartilage with a small bone fragment (fig 2c). It can occur at the attachments of both the patellar tendon inferiorly (common) and the quadriceps tendon superiorly (rare). The mechanism for injury is typically when there is resistance to a quadriceps contraction. Operative fixation is indicated if there is involvement of the patella articular cartilage or tendon retraction.

An acute event without previous pain helps to differentiate this entity from a more chronic process, Sinding-Larsen-Johansson disease Fig. 2 on page 8.

**Meniscal injury including discoid meniscus and displaced menisci**

*Discoid meniscus Fig. 4 on page 10*

A discoid meniscus represents an enlarged meniscus with further central extension onto the tibial articular surface. A discoid meniscus is diagnosed on MRI if the body of the meniscus is seen on three or more sagittal slices. Three distinct variants are recognised by the Watanabe classification: A complete discoid covers the entire tibial plateau, whilst a partial covers 80% or less. The Wrisberg variant has a thickened posterior horn, lacks the normal posterior meniscal attachments and can cause snapping knee syndrome; it is notoriously difficult to diagnose on MRI. Discoid menisci are prone to degeneration and tears.

The prevalence of meniscal tears increases with age. The incidence of meniscal tears in adolescents has increased because of increased sports participation and more widespread use of MRI. The medial meniscus is more firmly attached and is therefore more susceptible to meniscocapsular separation and tears.

*Meniscal tears Fig. 5 on page 11*

In children less than 10 years, a tear in a morphologically normal meniscus is rare. In adolescents with morphologically normal menisci, tears are often related to trauma and are commonly associated with ACL and MCL injuries, similar to adults.
Parameniscal cyst formation is associated with complete horizontal tears that extend to the periphery. This is thought to be related to direct communication with joint fluid. The morphology and terminology of meniscal tears is the same as in adults.

*Displaced meniscus Fig. 5 on page 11*

Several types of displaced meniscal tears are seen in adults and a similar pattern may be seen in adolescents participating in competitive sports. A flipped meniscal fragment occurs more commonly in the medial meniscus and is associated with a longitudinal tear.

The meniscal fragment is displaced centrally, posteriorly or anteriorly, while a portion of the fragment remains attached to the meniscus. If the fragment is flipped anteriorly, it may demonstrate the double anterior horn sign.

The bucket handle tear also typically occurs in the medial meniscus and is an extensive longitudinal tear in which the inner fragment is displaced centrally into the intercondylar notch. This is often demonstrated on MR as the double PCL sign (Fig 5d).

Inferiorly displaced flap fragments usually occur with horizontal tears. The displaced flap fragment is flipped inferiorly into the inferior para-articular gutter, which can also occur with a radial tear of the body. A meniscal flap can separate from the meniscus.

*Patella dislocation, subluxation and indirect injuries Fig. 6 on page 12*

Patella and trochlea morphology is vital in providing a stable and smooth platform for motion. The Wiberg classification is most widely used to describe articular morphology.

Patellar trochlea dysplasia is considered a developmental abnormality. Acute patella dislocation commonly results from a valgus flexion external rotation twisting motion; i.e. the femur rotates internally on a fixed foot whilst the knee is in flexion. The patient will complain of acute onset pain and may recognise the patella to be laterally dislocated; most commonly, this reduces when the leg is straightened.

The classical MRI oedema pattern results from impaction of the medial patella on the anterolateral femoral condyle. If the injury is severe an osteochondral defect may result in a loose body and internal derangement. The medial patellar structures, particularly
the medial patellofemoral ligament, must be carefully evaluated as it is of importance to determining the need for surgical therapy.

**Fractures around the knee** Fig. 7 on page 13

*Impaction fractures*

These can be divided into contiguous or non-contiguous injuries. Non-contiguous injuries are caused by the abrupt translation of two bones following ligamentous rupture\(^\text{13}\).

The direction and type of force can be inferred from the pattern of bone marrow oedema and soft-tissue injury.

Hayes et al (2000)\(^\text{13}\) classified this into 10 mechanism based patterns of injury: a) pure hyperextension b) hyperextension with varus c) hyperextension with valgus d) pure valgus e) pure varus f) flexion with valgus and external rotation g) flexion with varus and internal rotation g) flexion with varus and internal rotation h) flexion with posterior tibial translation i) patellar dislocation and j) direct trauma.

**Normal variants mimicking injury**

Cortical desmoids, also known as distal cortical femoral irregularities (DCFI) are a normal finding seen at the posteromedial aspect of the distal femoral metaphysis at the site of insertion of adductor magnus or origin of the medial head of gastrocnemius. They produce a scalloped appearance to the cortex thought to be due to a fibro-osseous reaction during rapid growth and minor traction, and are usually symmetrical\(^\text{15}\). There is often a small amount of apparent high-T2 signal which can mimic acute injury, however this is accepted as a normal finding.

Secondary ossification centres are typically found at the posterior aspect of the lateral femoral condyle and appear as ovoid intermediate-high T2 signal regions that can mimic an OCD (fig 1d and e). However at close inspection it is apparent that the overlying cartilage is completely intact and there is no surrounding bone marrow oedema.

**Images for this section:**
Fig. 1: Osteochondral defects (a-c) Unstable OCD in a 15 year-old boy with ongoing knee pain and no history of acute trauma. Large osteochondral defect within the lateral aspect of the medial femoral condyle demonstrates a high signal outer rim which is the same signal as fluid, a criteria for instability (black arrows b, c), in addition to numerous underlying cysts. (d-e) Incidental secondary ossification centre within the posterior aspect of the lateral femoral condyle. Note focal homogeneous signal abnormality within the subchondral region with no overlying cartilaginous defect and no surrounding bone marrow oedema.

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Fig. 2: Extensor mechanism avulsion injuries (a) Sinding-Larsen-Johansson. 15 year-old male gymnast with chronic knee pain. Sagittal PD-FS demonstrates marked fragmentation of the distal pole of the patella (arrow) with mild associated bone marrow oedema. The patella tendon appears relatively normal. (b) Acute patellar tendon sleeve avulsion fracture. 14 year-old boy presented with sudden onset severe pain over the inferior pole of patella following a jump with an extended knee. Sagittal PD-FS shows a high-signal fracture line at the inferior pole of the patella (white arrow) with separation of a sleeve of cortex inferiorly and cartilage posteriorly. There is also thickening and high-signal oedema within the patella tendon at the site of attachment suggestive of minimal disruption. Although appearances closely mimic chronic injury, history and examination helps differentiate acute injury. (c) Acute distal patella avulsion injury. A tiny cortical fragment has separated from the irregular tibial apophysis and the distal patella tendon appears oedematous with abnormal signal. As there was no retraction of the tendon this was treated conservatively. (d) Osgood-Schlatter disease. Corticated fragment adjacent to the tibial apophysis with only minor surrounding oedema and chronic thickening of the tendon. A more longstanding history aids differentiation.

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Fig. 3: Spectrum of ACL injuries in children and adolescents (a and b) 14 year-old boy sustained a twisting injury on a flexed knee during football. Sagittal T1 (a) and PD-FS (b) demonstrate a fracture fragment arising from the tibial spine, which is closely adjacent but appears separated from the tibial plateau (black arrows). This was surgically proven to be Type III tibial footplate avulsion injury. (c) Partial mid-substance and distal ACL tear. Sagittal PD-FS in a 14 year-old boy shows marked thinning of the ACL with extensive intrinsic (arrow) and surrounding signal abnormality in keeping with a significant partial tear. (d) Complete ACL rupture. Sagittal PD-FS in a 16 year-old boy following a football injury shows marked thickening and disruption of the anterior cruciate ligament with abnormal intrinsic high-signal on the PD-FS. No normal fibres were identified. Associated bone marrow oedema at the margin of the lateral femoral condyle confirms type of injury pattern.

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Fig. 4: Discoid meniscus (a-b) 15 year-old boy with severe pain over the lateral joint line following a hyper-extension injury during sports. Sagittal PD-FS images demonstrate a complete discoid lateral meniscus with visualisation of the body on over three images. There is a horizontal cleavage tear seen on all three images (posterior arrow in a) with an associated intrameniscal cyst (arrow b) and an anteriorly extrusion (a) which shows marked degenerate abnormal intramensical signal. (c-d) A complete discoid meniscus in an 8 year-old boy with a locking knee. Images show a thickened lateral meniscus (arrows c and d) with intrameniscal signal, a horizontal tear and posterior extrusion (arrow c).

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Fig. 5: Meniscal injury (a and b) Medial meniscal tear with flipped fragment in a 16 year-old boy following a football injury. (a) Demonstrates the double anterior horn sign due to a displaced meniscal fragment (arrow). A larger component of the displaced medial meniscal fragment is shown in (b). (c) Oblique tear of the posterior horn of lateral meniscus surfacing on the femoral aspect, confirmed at surgery. (d) Bucket handle tear of the medial meniscus with sagittal PD-FS images demonstrating a double-PCL sign (arrow d), displaced and separated bucket handle (e) with a displaced portion evident within the intercondylar notch (arrow f).

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**Fig. 6:** Patella dislocation in a 14 year-old girl who sustained an injury during netball landing on a flexed knee. (a) Axial PD-FS demonstrates a large osteochondral defect occupying the entire medial facet and part of the central and lateral portion of the posterior patella cartilage. Note contusion within the lateral femoral condyle from direct impact during patella dislocation, large patellofemoral knee joint effusion and abnormal signal within the medial patellofemoral stabilisers. (c) Sagittal PD again shows the large loose body within the joint.

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**Fig. 7:** Fractures around the knee. Spectrum of appearances of potential fractures encountered in adolescent sports-injuries. (a-c) Vertical-oblique fracture of the proximal tibial metaphysis coursing into the physis (Salter-Harris II) (arrows a and b), with an associated subperisoteal haematoma (arrowheads a and b). This was secondary to a further cortical break within the anterior tibia with associated micro-trabecular fracturing secondary to a direct impact injury. Note blood products within the haematoma on T1WI (arrowhead b). (d) Impaction injury and comminuted fracture of the anterior tibial...
apophysis almost reaching the tibial plateau (black arrow). (e, f) Lateral femoral trochlear cartilage defect (black arrows) due to recent transient patella dislocation. A loose body was also found within the joint (not shown) and surgically repaired. (g) Microtrabecular fracture of the lateral femoral condyle due to direct impact injury confirmed at surgery for associated meniscal tear. This appears only as apparent high-signal (*) bone marrow oedema and should be suspected in the correct clinical context. Note large effusion with fluid-fluid level.

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Conclusion

This educational exhibit outlines and illustrates the key patterns of injury in the knee in children on MRI.

References


