Injuries and normal variants of the pediatric knee

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Abstract: Knee pathology is a reason for consultation and a prevalent condition in children, which is why it is important to know both the normal variants as well as the most frequent pathologies. In this review a brief description is given of the main pathologies and normal variants that affect the knee in children, not only the main clinical characteristics but also the findings described in the different, most used imaging techniques (X-ray, ultrasound, computed tomography and magnetic resonance imaging [MRI]).

Keywords: Knee; Pediatrics; Bone lesions.

Introduction

Pediatric knee imaging studies are used to evaluate different conditions, whether traumatic, inflammatory, developmental or neoplastic.

At a younger age the normal evolution of the images during the skeletal development of the distal femur, proximal tibia and proximal fibula should be known to avoid diagnostic errors. Older children and adolescents present a higher frequency of traumatic and athletic injuries. During childhood and at school age, atraumatic conditions such as infections or inflammatory arthritis are observed, and not only neoplastic benign lesions but also malignant lesions should be considered as relatively common in the pediatric knee.

This review describes both normal variants and pathological findings related to the knee in the pediatric age.

Developmental and congenital variants without pathological significance

Distal femoral cortical irregularity

This is a benign fibro-osseous lesion, along the posteromedial distal femoral metaphysis, near the insertion site of the medial twin muscle or adductor magnus1. It is a common finding on radiography and magnetic resonance imaging (MRI), incidental, with more frequency between ages 10-15 years, although it can be present at any age until the physeal closure, after which it resolves1. In frontal radiography, it appears as a radiolucent, well circumscribed, cortical-based lesion with no associated soft tissue mass, with varying degrees of peripheral sclerosis, and on lateral projection an excavation or proliferation with cortical irregularity can be seen1. In MRI it presents low signal on T1 and high on T2 and may present enhancement with gadolinium1,2. It is surrounded by a hypointense ring corresponding to the peripheral sclerosis seen on radiography1. Because of the typical location and the radiographic findings, it does not require additional imaging nor treatment (Figure 1)1,3,4.

Normal femoral condylar ossification

Differentiating the normal ossification of the medial and lateral condyles of the epiphyseal pathology, especially the osteochondritis dissecans, is a frequent challenge when analyzing pediatric knee radiographs.
The irregular ossification in the posterior central portion of the lateral femoral condyle is a variant of normal development common in children younger than 10 years (Figure 2). Osteochondritis dissecans presents predominantly in the medial femoral condyle, in children older than 10 years, in the middle third of the condyle (and not posterior, as in normal condylar ossification) and edema is frequent.

**Developmental and congenital variants that may have pathological significance**

**Discoid meniscus**

This is a frequent congenital variant, multifactorial, with an estimated incidence of 0.4 to 17%\(^1,5\). The discoid meniscus is long, dysplastic, does not have the normal semilunar form, commonly affects the lateral meniscus and may be partial or complete\(^1,2,6\). Clinically it manifests in children and adolescents with pain, click, popping or locking of the knee\(^2\). The lateral discoid meniscus is more frequently associated with meniscal injuries, possibly due to differences in both mechanical function and histological changes\(^5\). In coronal MRI slices the meniscus extends medially towards the tibial spine (greater than 13 mm of transverse diameter or 2 mm greater than the normal medial meniscus)\(^2\). In sagittal slices the continuity between the anterior and posterior horns is seen in 3 or more contiguous images in slices of 4 to 5 mm thickness\(^2,6\). Most meniscal injuries in children under 10 years are secondary to discoid meniscus (Figure 3)\(^5\).

![Figure 1. Distal femoral cortical irregularity. AP radiograph and sagittal fat suppressed T2 MRI. Radiolucent lesion, well defined, with sclerotic margins, cortical base, on the posteromedial distal femoral metaphysis.](image1)

![Figure 2. Normal femoral condylar ossification. Coronal and sagittal CT bone window. Irregular ossification in the posterolateral portion of the lateral femoral condyle as a normal variant.](image2)
Bipartite patella

The patella is normally formed of 2 or 3 ossification centers, which begin to develop between 4 and 7 years of age\(^2,7\). In the bipartite patella the secondary ossification center at the superolateral aspect does not merge, which can be uni or bilateral\(^2\). It is considered a normal variant, but can be painful in both acute and chronic stress injuries that can interrupt the synchondrosis between the accessory ossification center and the patella\(^2,4,6,7\). In radiography a fragment not attached to the rest of the patella can be seen, well corticated and generally along the superolateral pole (Figure 4).

Blount’s disease

Abnormal endochondral ossification of the medial proximal tibia leads to Blount’s or tibia vara disease. Radiography is sufficient for the diagnosis in pediatric patients who present genu varo after 2 years of age. The proximal tibia presents an epiphyseal-physeal-metaphyseal distortion, with medial inclination and fragmentation of the epiphysis, widening and irregularity of the physis and rounded or pointed metaphysis, resulting in an increase in the metaphyseal-diaphyseal angle. It presents long-term complications, such as premature degenerative changes secondary to progressive deformity, altered biomechanics or leg length
discrepancy if there is no appropriate treatment. The early or infantile form and the late or juvenile form differ if the symptomatology occurs before or after 4 years of age respectively.

**Anomalies of patellar alignment**

**Impingement of superolateral Hoffa’s fat pad**

This corresponds to the friction syndrome of the lateral femoral condyle with the patellar tendon in the context of patellofemoral misalignment (a combination of alterations affecting the anterior extensor mechanism which includes a high patella, patellofemoral dysplasia and lateralization of the tibial tuberosity). It is most commonly seen in adolescent girls aged between 15-16 years with chronic anterior knee pain, and the most common structural abnormality observed is the high patella (patellar / patellar tendon ratio greater than 1.3 in men and 1.5 in women in sagittal MR imaging or an Insall-Salvati index on lateral projection of knee x-ray greater than 1.2). In MRI images, an increased signal in T2 was observed in the Hoffa fat pad (Figure 5).

**Acute lateral patellar dislocation**

This is a consequence of poor patellar alignment. Acute patellar dislocation is one of the most common injuries affecting the pediatric knee. Lateral luxation is typically transient, but the patella rarely remains dislocated in the initial images. After reduction, the frontal and lateral radiographs sometimes show only increased volume of soft tissue and joint effusion. In flexion, the patella moves laterally injuring the medial static stabilizers of the patella, which can lead to osteochondral avulsion fractures of the medial patellar pole and ligament or retinacular ruptures. The impaction of the patellar articular cartilage on the lateral femur may result in osteochondral fracture of the patella, trochlea, or lateral femoral condyle. In extension, the patella moves medially and impacts the anterolateral femoral condyle resulting in the classic pattern of edema in the lateral femoral condyle (Figure 6).

**Trauma**

In adults, traumatic lesions most frequently produce ligament and meniscal injuries, unlike children and adolescents in whom it characteristically affects the physis and adjacent bones, which are the weakest sites. This is why the pediatric knee is more susceptible to multiple types of fractures, some exclusive to this age, together with chronic stress injuries.

**Acute trauma**

**Fissure fractures**

The distal femoral physis is responsible for 70% of the growth of the femur and 35% of the growth of the entire lower extremity. It is the fastest growing physis, with an average of 10 mm/year. Before skeletal maturation, physeal fractures are more frequent than ligamentous lesions. Those fractures which affect the proximal femoral or distal femoral physis have a high risk of causing alterations in growth, with the consequent development of discrepancy in the length of the lower extremities and/or angular deformities. These can be subtle in radiography and require MRI for a better characterization. Fissure fractures may occur until the physis is close to closure. Salter-Harris II fractures of the distal femur are the most common fractures (Figure 7).
Avulsion fractures of the tibial spine
The most common avulsion fracture of the immature skeleton of the knee is that of the tibial spine. This is due to the composition of the tibial spine at this age, which is weaker than that of the anterior cruciate ligament. Prior to the physeal closure, avulsion of the anterior tibial spine is relatively common, whereas anterior cruciate ligament rupture becomes more prevalent after physeal closure. The width of the intercondylar notch would also play a role in the type of injury, where the avulsion is more frequent in patients with wider intercondylar notch. They can be subtle on radiography and initially only diagnosed with MRI.

Lesions of the anterior cruciate ligament
Ligament injuries are generally less frequent in pediatric patients due to ligamentous laxity, coupled with the relative weakness of the physis, which makes bone lesions much more common. Anterior cruciate ligament injuries are common in adolescents and more frequent in girls due to the combination of hormonal influence, valgus alignment and increased joint laxity. The rupture criteria are the same as for adults, the loss of parallelism with the Blumensaat line being a more sensitive finding than the discontinuity of the fibers in this age group.

Anterior bursitis of the knee
There are 12 bursae around the knee, of which 4 are more susceptible to inflammation (prepatellar, superficial infrapatellar, deep infrapatellar and pes anserine (goose’s foot)).

Chronic trauma
Chronic lesions of the extensor mechanism of the knee include Osgood-Schlatter disease and Sinding-Larsen-Johansson disease.

Osgood-Schlatter Disease
This is a traction apophysitis after repeated trauma in the patellar tendon insertion in the tibial tuberosity, at an early stage of tubular ossification. The typical presentation is an adolescent male with pain on the anterior aspect of the knee and increased volume on the tibial tubercle. In MRI, a signal increase is observed in the ossification center of the tibial tubercle at an early stage of the disease, which then extends to the adjacent physeal cartilage. The patellar tendon appears edematous and thickened in its insertion in the tuberosity, a finding also visible on radiography. In ultrasound the findings are: fragmentation of the ossification center of the tuberosity, thickening of the patellar tendon and reactive bursitis. In the final stage, separate ossicles...
Sinding-Larsen-Johansson disease

This is a traction apophysitis that affects the origin of the patellar tendon in the lower pole of the patella, which represents a chronic traction injury of the immature bone-bearing junction. It is typically seen in athletes aged between 10-14 years and may present with pain in the lower pole of the patella associated with increased soft tissue volume and lower patellar pain, often associated with running, climbing or kneeling. The bone fragments adjacent to the inferior pole of the patella are seen on radiography. MRI shows fragmentation of the inferior patellar pole associated with thickening and edema of the proximal patellar tendon and also high T2 signal of the Hoffa fat pad. In ultrasound the findings are: thickening of the patellar tendon in its proximal aspect, fragmentation of the inferior pole of the patella and bursitis. Treatment is symptomatic. The avulsion lesions of the inferior patellar pole are known as Sinding-Larsen-Johansson's disease before the physeal closure, and as jumper’s knee after closure (Figure 11).

Juvenile osteochondritis dissecans

It is thought to be an acquired lesion of the subchondral bone characterized by varying degrees of bone resorption, collapse and abduction formation unrelated to an acute osteochondral fracture. It is defined as juvenile if it occurs before the closure of the physi. Injury and separation of an intraarticular fragment of subchondral bone occurs with or without disruption of the overlying articular cartilage. The
most common site in children and adults is the lateral aspect of the medial femoral condyle. The presentation is usually nonspecific, with poorly localized gonalgia that increases with exercise or climbing hills or stairs. In the physical examination, an antalgic position and pain on palpation over the anteromedial aspect of the knee in flexion, is observed. Up to 25% have bilateral pain. The initial imaging method is the anteroposterior radiograph (AP), lateral and tunnel projection, where in lateral and tunnel projection posterior femoral condyles are assessed which are not clearly seen in the AP projection. MRI is sensitive to show the subarticular bone defect in the early stages of the process. The presence of mechanical symptoms, joint effusion, crackles and pain with movement may suggest instability of the lesion. Quadriceps atrophy is an indicator of chronicity (Figure 12).

**Figure 12. Juvenile osteochondritis dissecans. AP and lateral radiography. Radiolucent osteochondral defect in the medial femoral condyle.**

**Inflammatory pathology**

In the context of pain, lameness and edema, children are frequently evaluated for possible infectious or inflammatory arthritis. The presence of joint effusion may have multiple underlying non-traumatic causes including septic arthritis, juvenile inflammatory arthritis and hemophilia as more frequent causes.

**Septic arthritis**

This is a rapidly progressive inflammatory arthritis most commonly caused by Staphylococcus aureus. More frequent in small children, with a peak at 2-3 years. The joints of the lower extremities are the most affected. Patients present with abrupt onset of fever, edema, local heat over the joint and functional impotence. Given the clinical suspicion of joint involvement, ultrasound plays an important role in evaluating the magnitude of the effusion, the characteristics and synovial vascularization by color Doppler. In MRI, associated bone involvement (osteomyelitis and / or subperiosteal abscess) can be identified as the presence of signal anomalies and enhancement in the adjacent bone suggest associated osteomyelitis (Figure 13).

**Osteomyelitis**

The most frequent clinical history is fever associated with decreased use of the affected limb. Older children
may be able to identify the specific site of infection. In the anatomical distribution of acute bacterial osteoarticular infections in children, the knee is affected in 25 to 40%. The origin may be hematogenous, from a source of contiguous infection, penetrating or puncture injuries or postoperative infections.

Although conventional radiography is recommended in all cases (may rule out an underlying fracture, for example), its sensitivity in acute infection is extremely low, since the findings do not appear until 50% of the bone material has been lost, 10 days after the onset of the symptoms. The imaging findings are ill-defined radiolucent lesions resulting from the destruction of the metaphysis and sclerotic images secondary to periostitis.

MRI is sensitive for identifying edema and cortical inflammation and the bone marrow. The major advantage is that it delivers high-quality images of the bone, the joint and the surrounding tissue, critical information for deciding whether surgery is necessary (Figure 14)\textsuperscript{16}.

**Hemophilia**

It is a recessive disease linked to the X chromosome that manifests itself as a deficiency of coagulation factors. Hemophilia A is due to factor VIII deficiency and hemophilia B, due to factor IX deficiency. Spontaneous bleeding or minimal

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**Figure 13.** Septic arthritis. X-ray in lateral projection. Increased volume in the knee joint and joint effusion.

**Figure 14.** Osteomyelitis. Coronal CT bone window and axial window of soft tissue. Increased density and irregularity of the epiphysis cortex and proximal metaphysis of the tibia with presence of a possible Brodie’s abscess. Dense foreign body in the subcutaneous cellular tissue in the anterior portion of the proximal tibial metaphysis.
trauma occurs. 85% of bleeding episodes are hemarthrosis, and the knee is the most affected joint followed by the elbow, the ankle, the hip and the shoulder. Recurrent episodes of bleeding can cause synovial hypertrophy and inflammation, together with bone and cartilage erosions which lead to early degenerative changes. In MRI, the synovium is thickened and with low signal on T1 and T2 for hemosiderin deposition, which gives the characteristic blooming of low signal in echo gradient. Foci of T2-weighted signals within the synovium represent inflammation. The epiphyses appear larger and the patella appears square as in juvenile rheumatoid arthritis. The intercondylar notch is also widened. Chronically, thinned cartilage, subchondral cysts and osteophytes can be seen. Ultrasonography has high sensitivity for evaluating synovial hypertrophy and a borderline sensitivity (70%) for detecting small amounts of effusion compared to MRI (Figure 15).

Figure 15. Hemophilia. Sagittal T2 MRI. Arthropathy with synovial thickening and hyposignal foci representing deposits of hemosiderin in the joint space in the context of hemophilic arthropathy. Joint effusion.

Juvenile rheumatoid arthritis

Systemic disease affecting children under 16 years of age with symptoms older than 6 months. The knee is the most affected joint; presents pain, local heat and volume increase. MRI is used to determine activity of the disease, its extent and the response to treatment.

The most common findings in MRI are: joint effusion, synovial thickening and nodularity, pannus formation and inflammation of the infrapatellar fat. The thickened synovial and pannus show enhancement with gadolinium. With the progression of the disease, changes in cartilage and bone are observed as a decrease or loss of joint space and bone erosions. In a chronic stage, the degree of synovial thickening depends on both the underlying inflammatory process and the surrounding degenerative changes.

Neoplastic pathology

Fibrous cortical defect and non-ossifying fibroma

These are the most frequent benign lesions of the pediatric skeleton and often incidental findings on radiography. They are common metaphyseal lesions around the knee with identical histology. It is called a fibrous cortical defect if it measures less than 2 cm and non-ossifying fibroma if it measures more than 2 cm. The characteristic radiographic appearance is a lytic lesion with well-defined sclerotic margins, eccentric and cortical-based. As the injury matures, its sclerotic component increases. The MRI signal varies depending on the degree of
maturation. They have high signal on T2 in the early stage, then heterogenous and finally low signal when the lesion is mature. These characteristics correspond to the initial radiolucent appearance on radiography and later with sclerosis. Large non-ossifying fibromas can be complicated by pathological fractures (Figure 16).

**Osteochondroma**

These are frequent injuries around the knee that arise when the growth cartilage plate begins to move towards the metaphyseal region. It is an extension of normal bone showing continuity with the periosteum, cortex and medulla of the underlying bone. The majority can be diagnosed only by radiography because of the characteristic of cortical and medullary continuity with the native bone. They may cause local complications by effect of mass such as bursitis (developing bursae on these tumors at the sites of friction), compression of the neurovascular package and formation of pseudoaneurysms (Figure 17).

**Chondroblastoma**

It is a rare benign tumor of immature cartilage, with a peak incidence between 10 and 20 years of age. About 50% of these tumors are diagnosed in patients with an immature skeleton. It has a predilection for the epiphyses of the long bones, with the bones around the knee being most frequently affected. They often traverse the growth plate toward the adjacent metaphysis. On x-ray the lesion is eccentric, lytic, with geographic borders. Some calcifications can be seen within the lesion reflecting chondroid matrix (Figure 18).

**Osteosarcoma**

It is the most frequent malignant primary bone neoplasm around the knee. It is usually observed in the second decade of life and typically presents as a painful mass. The origin is usually metaphyseal and medullary. The most common site is found in the long bones of the lower limb, especially around the knee, followed by the humerus. Radiography shows aggressive lytic bone lesions, blastic or mixed with indistinct margins, cortical destruction, aggressive periosteal reaction and soft tissue mass. It is characterized by production of osteoid matrix. MRI is crucial for the local staging and to determine the extent of bone marrow, transphyseal, intraarticular, and soft tissue involvement (Figure 19).

**Ewing’s sarcoma**

It is the second most common malignant primary bone tumor of infancy and young adults after osteosarcoma. It is a primitive neuroectodermal tumor that is observed in the axial and appendicular skeleton with the same frequency, whereas the vast majority of the osteosarcomas occur in the appendicular skeleton. Within the long bones it is generally observed in the diaphysis and metaphysis. On radiography it has a variable but generally aggressive appearance. The imaging findings include a permeative, mixed lytic-sclerotic appearance with destruction of the cortical and aggressive periosteal reaction (spiculate or onion skin). It does not usually produce a mineralized osteoid matrix as seen in osteosarcoma. MRI is crucial for local staging and evaluation of skip lesions. It is hypointense to the muscle in sequences sensitive to liquid due to its dense cellularity. A lytic lesion in
Figure 18. Chondroblastoma. X-ray in AP projection. Oval lytic lesion at the proximal end of the tibia, compromising part of the metaphysis and epiphysis in relation to the medial tibial plate.

Figure 19. Osteosarcoma. X-Ray in AP and lateral projection (a) and FAT SAT T1 sequence MRI with coronal and sagittal gadolinium (b). Distal femoral metadiaphyseal focal bone lesion, mixed, predominantly sclerotic, ill defined, associated with areas of cortical destruction, poorly delimited margins and aggressive periosteal reaction.
a child associated with a large mass of soft tissue should be suspected of being an Ewing’s sarcoma. A curative treatment is possible in approximately two-thirds of patients with localized Ewing’s sarcoma; however, the prognosis in patients with metastatic disease is poor.

Conclusion
The knowledge of the normal variants of the development and of the exclusive or more frequent pathological conditions in the pediatric knee will allow a better interpretation of the imaging studies that are performed in children, as well as to differentiate those pathologies that require only x-ray for its diagnosis and to focus the MRI for uncertain findings or more precise indications about the extent of the evaluated lesion.

Ethical Responsibilities
Protection of people and animals. The authors declare that no experiments have been performed on humans or animals for this research.
Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.
Right to privacy and informed consent. The authors declare that no patient data appears in this article.

Conflict of interests
The authors declare no conflict of interest.

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