MR IMAGING FINDINGS OF LESIONS INVOLVING CARTILAGE AND BONE IN THE PAEDIATRIC KNEE: A PICTORIAL REVIEW

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The knee is the joint which is most commonly imaged by MRI in children and adolescents.
With increasing participation in competitive sports, traumatic knee injuries with osteochondral lesions are increasingly common in children. However, it is also important to exclude non traumatic conditions that result in defects of the articular cartilage and/or subchondral bone plate or growth plate of the knee, since timely diagnosis and therapy may help prevent lifelong disability in these patients. Moreover, there are normal variants that occur in the ossifying knee that should not be mistaken for lesions.
The aim of this essay is to review the wide range of conditions that may result in MRI signal changes of the ossifying knee in children.

Musculoskeletal injury in children is common and can lead to lifelong disability. The knee joint is often involved in sports-related as well as in non traumatic pathological conditions in the paediatric population.

Magnetic resonance imaging (MRI) is the imaging investigation of choice due to the absence of radiation, multiplanar imaging options, high image resolution and superb soft tissue contrast. MRI visualizes the cartilaginous ends of growing bones, bone marrow and supporting soft tissue structures making it ideally suited for evaluation of bone and cartilage injury and the complicating growth disturbance in young patients (1).

Although several of the injuries in the paediatric knee occur in adults as well, the paediatric knee is also subject to unique developmental and pathological processes which may be related to the presence of unfused physes (2). Musculoskeletal lesions can be the first manifestation of systemic disease. Also, there are normal findings of the growing and developing femoral condyle such as ossification variants that are not seen in the adult population and should be differentiated from pathology (3).

The aim of this pictorial review is to familiarize the reader with the MR imaging features of the wide variety of lesions that may result in damage to the cartilage and bone in the paediatric knee.

1. Traumatic paediatric knee lesions

1.1. Chondral injury

Cartilaginous injuries are the most common lesions after acute knee trauma in skeletally immature

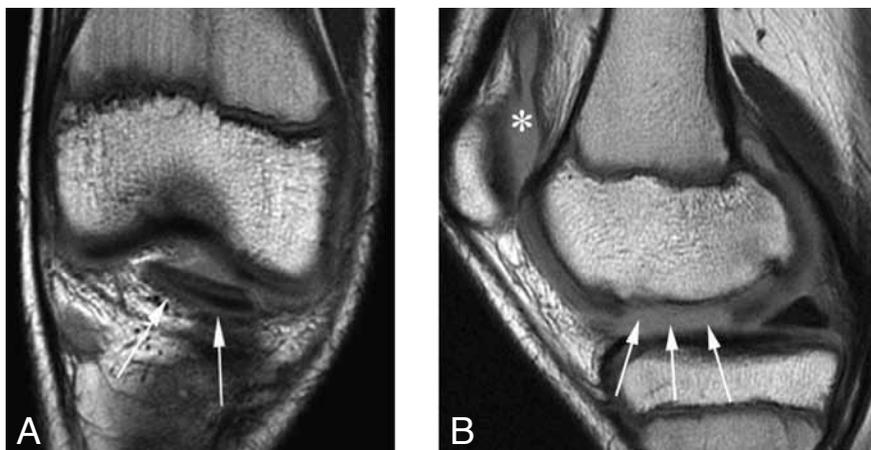Fig. 1. — Chondral fracture in an 11-year-old boy.
A. Coronal T1-weighted image demonstrates a large loose body (arrows) with signal intensity f cartilage in the femorotibial joint space.
B. Sagittal T1-weighted image demonstrates the avulsed osteochondral fragment (arrows) anteriorly in the femorotibial joint space. Note the presence of hydrops (asterisk).

patients. These lesions are often subtle but can be significant clinically and may easily remain undetected. It is important to include MRI sequences that are sensitive to articular cartilage injury in the evaluation of internal derangement of the paediatric knee (4).

1.1.1. Chondropathy

MRI shows chondropathy as focal cartilaginous thickening, superficial or deep ulceration or fissuring and demonstrates associated bone bruise and osteochondral separated fractures (5).

1.1.2. Chondral fracture

With shear stress mechanism of injury, chondral avulsion fracture may occur. A focal defect in the articular cartilage and the presence of a cartilaginous fragment in the joint space may be demonstrated (Fig. 1a-b).

1.2. Physeal Fractures

Approximately 15% of all paediatric fractures involve the physis (6). MRI demonstrates the cartilaginous path of the fracture, as well as associated findings (7). Nearly 15% of all physeal fractures lead to growth arrest with the formation of a bone bridge across the physis, causing subsequent limb shortening or angular deformity. The distal femur (1.4%) and proximal tibia (0.8%) are infrequent sites of physeal fracture, but have high incidences of post-traumatic premature physeal fusion (35% and 16% respectively) (1).

1.3. Temporary Patellar Dislocation (TPD)/Patellar subluxation

TPD is often an unexpected finding on MRI of the knee in children. Paediatric manifestations of TPD
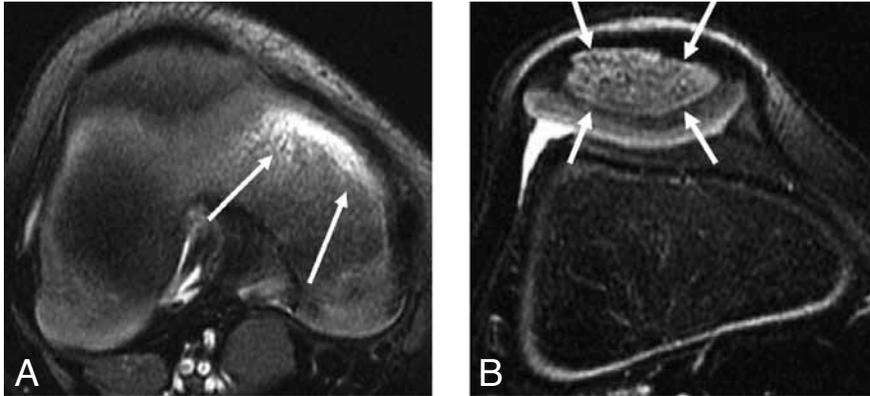
Fig. 2. — Temporary patellar dislocation (patellar subluxation) in a 7-year-old girl.
Axial T2-weighted image with fat saturation demonstrates bone marrow edema (arrows) in (A) the lateral femoral condyle and (B) in the entire patella.
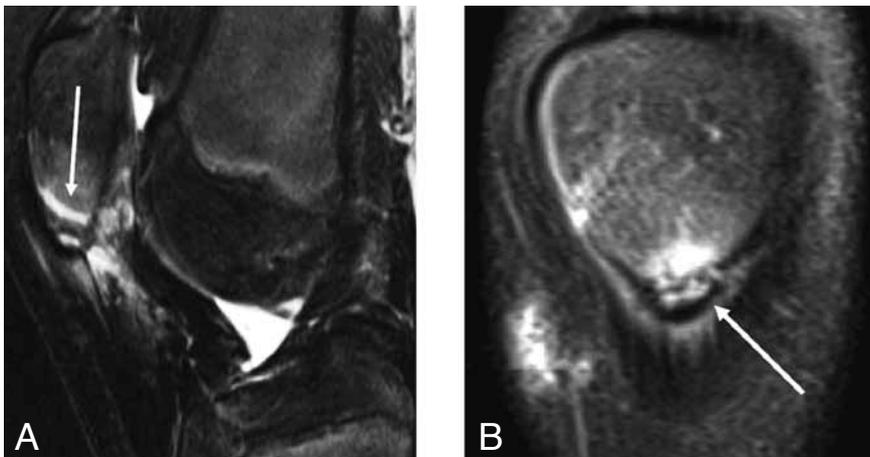

Fig. 3. — Patellar sleeve avulsion in a 10-year-old boy.
A. Sagittal and (B) coronal T2-weighted images with fat saturation demonstrate a hypointense fracture line with surrounding bone marrow oedema (arrows) in the inferior aspect of the patella.

seen on MRI are similar to those in adults. Bone bruising of the infero-medial patella and the lateral femoral condyle (kissing contusions), cartilage injuries of the inferomedial patella and the lateral femoral condyle, osteochondral fragments and injuries of the medial patellar restraints are the most common findings of TPD on MRI (Fig. 2a-b) (2, 8).

1.4. Patellar sleeve avulsion

The composition of the ossifying patella renders it weaker than the patellar tendon. Rapid forceful contraction of the quadriceps against resistance in partial flexion of the knee can result in avulsion fracture of the inferior patellar pole. The typical patient is 9 to 12 years old and presents with acute inferior patellar pain. The cartilaginous injury is always much more extensive than the avulsed fragment of ossified bone (Fig. 3a-b) (9). Patella alta may

be present if the avulsion is complete. In some cases the avulsed fragment may be entirely cartilaginous and therefore occult on radiography. MRI establishes the extent of the cartilaginous injury and delineates joint involvement and the degree of fragment displacement. This information can be useful diagnostically and in guiding therapy. Treatment involves prompt surgical reduction and internal fixation of the disrupted patellar tendon. If a bony fragment is visible on conventional radiography and the displacement is less than 2 mm, closed treatment in a cast in extension is justified (10). Injuries at the superior patellar-quadriceps junction also occur but are less frequent (9).

1.5. Tibial spine avulsion fracture

Tibial spine avulsion fractures are common before physeal closure (Fig. 4a-b). In paediatric athletes,

trauma with stretched ACL may result in avulsion of the tibial spine. The composition of the tibial spine in children renders it weaker than the ACL (11). Non-operative versus surgical management is determined by the degree of displacement of the osseous fragment and is controversial in skeletally immature athletes because the reconstruction technique requires crossing of the growth plate (5).

1.6. Osteochondritis dissecans (OCD)

Repetitive microtrauma is felt to play a role in the etiology of juvenile OCD. The lesion is thought to be an osteochondral fracture with avascular necrosis of subchondral bone and overlying cartilage (Fig. 5). In the knee, OCD most commonly affects the lateral aspect of the medial femoral condyle (3). MRI confirms the diagnosis and evaluates the stability of the lesion (12). A high T2 signal intensity rim surrounding a juvenile OCD lesion indicates instability if it has the same signal intensity as adjacent joint fluid, if it is surrounded by a second outer rim of low T2 signal intensity, or if it is accompanied by multiple breaks in the subchondral bone plate on T2-weighted images. Cysts surrounding the lesion indicate instability only if they are multiple or large in size (> 5 mm) (13, 14).

MRI can assess the integrity of the overlying cartilage and identifies the presence of loose bodies in the joint (15). OCD must be differentiated from normal variants of ossification in the paediatric knee, most commonly seen at the posterior aspect of the lateral femoral condyle without associated bone marrow oedema (16, 17).

2. Non-traumatic paediatric knee lesions

2.1. Infection

Infection of the musculoskeletal system in children is challenging. In the appropriate clinical context, the main responsability for the radiologist is to raise the possibility of infection when reporting conventional radiography or ultrasound studies and to select the appropriate next imaging modality to confirm diagnosis. Since no single MRI feature can differentiate septic from non septic arthritis, biopsy may be warranted in the work-up of these lesions (18-20).

2.1.1. Septic arthritis

A missed diagnosis of septic arthritis of the knee in children may lead to severe long-lasting sequelae
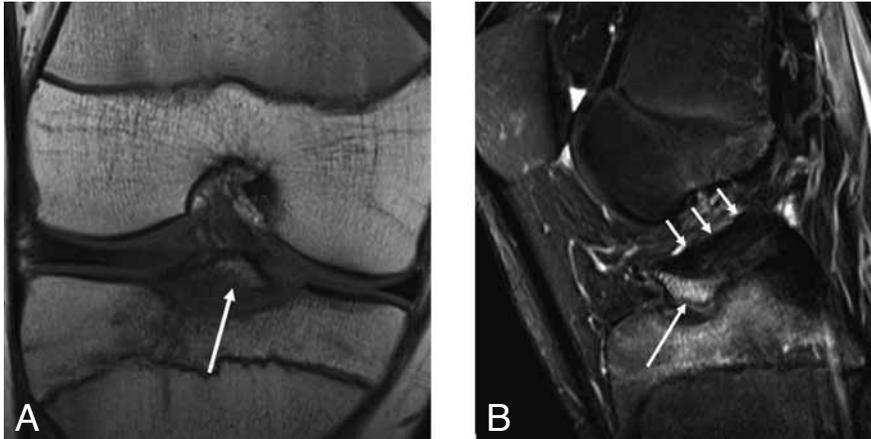
Fig. 4. — Tibial spine avulsion in a 14-year-old boy.
A. Coronal T1-weighted image and (B) sagittal T2-weighted image with fat saturation demonstrate avulsion fracture of the tibial spine (long arrows) with bone marrow oedema of the fracture fragments. There is no tear of the anterior cruciate ligament (short arrows).
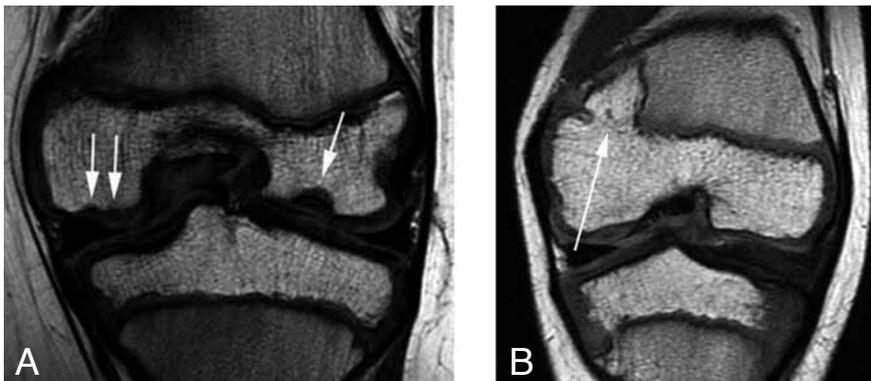

Fig. 5. — Osteochondritis dissecans in an 11-year-old boy.
Sagittal Pd-weighted image demonstrates a large osteochondral lesion (long arrows) surrounded by a rim of high signal (short arrows) and multiple small perilesional cysts (arrowhead) in keeping with unstable OCD. Note the lesion extends along the middle and posterior third of the femoral condyle.

Fig. 6. — Bone and cartilage lesions due to septic arthritis of the knee in (a) an 9-year-old boy and (b) in a 7-year-old girl.
A. Coronal T1-weighted image demonstrates ill-defined osteochondral defects (arrows) in the medial and lateral femoral epiphysis.
B. Coronal T1-weighted image demonstrates a large bony bar of the distal epiphysis of the femur (arrow) following meningococcus septic arthritis of the knee.

and disability. In young patients with an acutely swollen knee joint, the diagnosis of septic arthritis must always be excluded. If sepsis is suspected, urgent joint aspiration is mandatory since early appropriate treatment is curative (18). Numerous investigations including plain radiographs, US, CT and MRI may be needed for diagnosis and to guide therapy. It is important to realize that changes on conventional radiography are only seen in late stage disease, therefore negative radiographs do not exclude septic arthritis. US, CT or MR guided percutaneous biopsy may obtain the causative micro-organism (19). Although no single MRI feature can differentiate septic from non septic arthritis, the presence of several abnormal findings increases the probability of infection (20). Bone erosions appear earlier compared with non septic arthritis. Concomitant bone erosions and marrow oedema are highly suggestive of septic arthritis, and the added presence of synovial oedema and thickening, soft tissue oedema or bone marrow enhancement is even more suggestive of infection (Fig. 6a-b) (21). Joint effusion can be present in both septic and non septic joints, up to one third of patients with septic arthritis lacks a joint effusion. Abnormal marrow signal is worrisome for concomitant osteomyelitis, especially if diffuse and visible on T1-weighted images (22).

2.1.2. Osteomyelitis

MRI is not suitable for screening in paediatric osteomyelitis, but it first choice imaging modality for complementary examination if there is a clinical suspicion but conventional radiography is negative. MRI can also be guided by other imaging studies (eg. Tc bone scan in case of suspected chronic recurrent osteomyelitis).

In osteomyelitis, the tubular bones are most of the time affected at the metaphysis level, but epiphyseal involvement may occur as well (19). In early osteomyelitis bone marrow oedema is present, enhancing with IV Gadolinium administration. There is usually a poor delineation between normal and abnormal bone marrow. In chronic osteomyelitis, there is a sharp differentiation between normal and abnormal soft tissues surrounding the bones. Gadolinium enhancement delineates intraosseous and soft tissues abscesses and collections. Infection extending to the growth plates is ideally demonstrated in the coronal or sagittal imaging planes. Underlying preexisting conditions include sickle cell disease, immunodeficient state and chickenpox (19). CRMO (Chronic recurrent multifocal osteomyelitis) is considered part of the SAPHO syndrome (synovitis, acne, pustulosis, hyperostosis, osteitis). In CRMO, multiple foci of osteocondensation and osteolysis with ill-defined bone marrow edema involving metaphysis and diaphyses are seen (19).
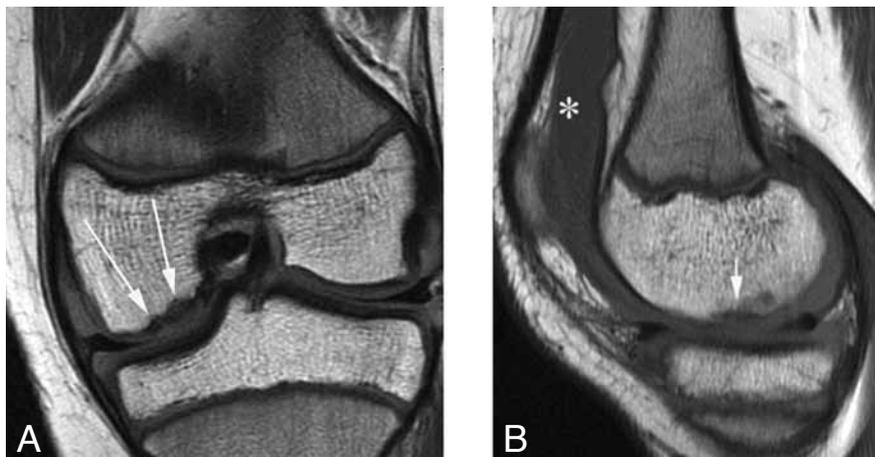
Fig. 7. — Juvenile arthritis of the knee in a 9-year-old girl.
A. Coronal T1-weighted image demonstrates a subchondral lesion (arrows) in the medial femoral epiphysis.
B. Sagittal T1-weighted image demonstrates a subchondral lesion (arrow) in the weight-bearing aspect of the medial femoral epiphysis. Note the presence of a large joint effusion (asterisk).
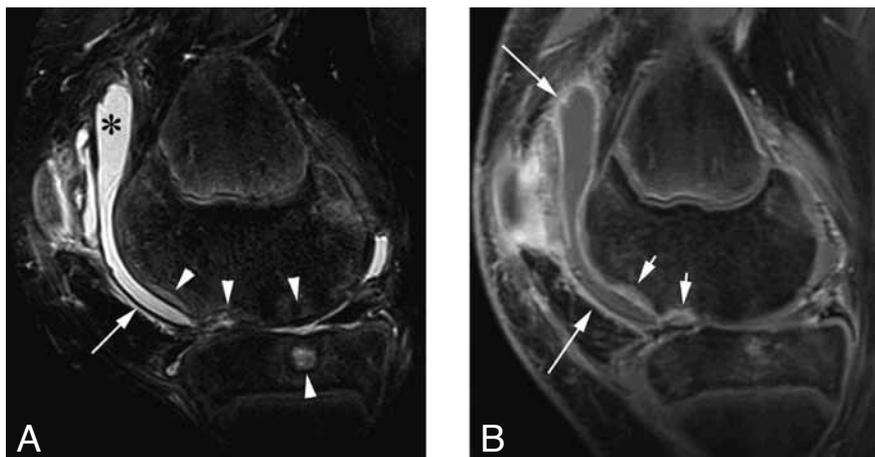

Fig. 8. — Haemophiliac arthropathy of the knee in a 13-year-old boy.
A. Sagittal T2-weighted image with fat saturation demonstrates several ill-defined subchondral lesions and a subchondral cyst (arrowheads) in the lateral femoral epiphysis and lateral tibial epiphysis. Hemosiderin staining is demonstrated as a T2 hypointens lining of the synovium (arrow). Moderate to large joint effusion is present (asterisk).
B. Sagittal T1-weighted image with fat saturation after IV contrast administration demonstrates ill-defined subchondral lesions (short arrows) in the medial and lateral femoral epiphysis. The synovium enhances and is slightly thickened (long arrows).

2.2. Inflammatory disease

A variety of conditions may result in cartilagenous or bony lesions of the knee due to synovial inflammation, including juvenile idiopathic arthritis (JIA), haemophilia, pigmented villonodular synovitis (PVNS) and intraarticular vascular lesions. Clinical presentation may be suggestive. Patients with JIA classically present with persisting articular inflammatory symptoms > 6 weeks, with onset before the age of 16-years-old and may present with chronic uveitis, arthritis of the temporomandibular joint or cervical spine ankylosis. Anemic symptoms in patients with hemophilia also suggest the correct diagnosis (3).

2.2.1. JIA

Juvenile idiopathic arthritis (JIA) is the most common chronic rheumatic disease of childhood and is an important cause of short-term and long-term disability (23). The radiologist has an important role in suggesting the diagnosis of JIA as the clinician may not be aware of the condition (24). Moreover, MRI may play a role in therapy monitoring. The early MRI features of JIA in the knee joint are irregularity of the infrapatellar fat pad, lymphadenopathy, ill-defined areas of bone marrow oedema and joint effusion. If these features are present gadolinium can be administered to assess the degree of synovial hypertrophy.

Erosions are one of the endpoints of the disease process in JIA and indicate destruction of both bone and cartilage (Fig. 7a-b). Erosions can occur at any point along the articular surface of the bone but are most often seen at the insertion site of the intraosseous ligaments and at the sites of synovial reflection, as these areas have relatively less overlying protective cartilage (25). Erosions are seen as well circumscribed lesions with low T1 and high T2 signal, often showing marked enhancement following gadolinium administration (26). Differential diagnosis with septic arthritis is often challenging and biopsy may be necessary (20).

2.2.2. PVNS (Pigmented villonodular synovitis)

PVNS is a mono-articular process involving the knee in 80% (27). With PVNS, synovial proliferation and signal loss due to chronic hemosiderin deposition is demonstrated. The latter finding is accentuated on gradient echo imaging due to magnetic susceptibility artefact, known as 'blooming'. Contrast-enhanced imaging is useful in diagnosis and assessment of the lesion extent of PVNS in paediatric patients (28). MRI features are particularly useful for differentiating PVNS from hemophilia. Differential diagnosis includes hemophilia (typical clinical history) and hemangioma (presence of serpentine vascular channels) (27).

2.2.3. Haemophilia

Haemophiliac arthropathy due to recurrent haemartrosis is the main clinical feature of severe haemophilia and a major cause of morbidity in this group of patients. The most common findings in haemophiliac arthropathy of the knee are joint effusion, synovial hypertrophy, synovial haemosiderin deposits and osteochondral lesions resulting in joint space narrowing (Fig. 8a-b). The latter finding is accentuated on gradient echo imaging. MRI clearly depicts these changes, which may not be identified by conventional radiography in early stages, even before the presence of symptoms.
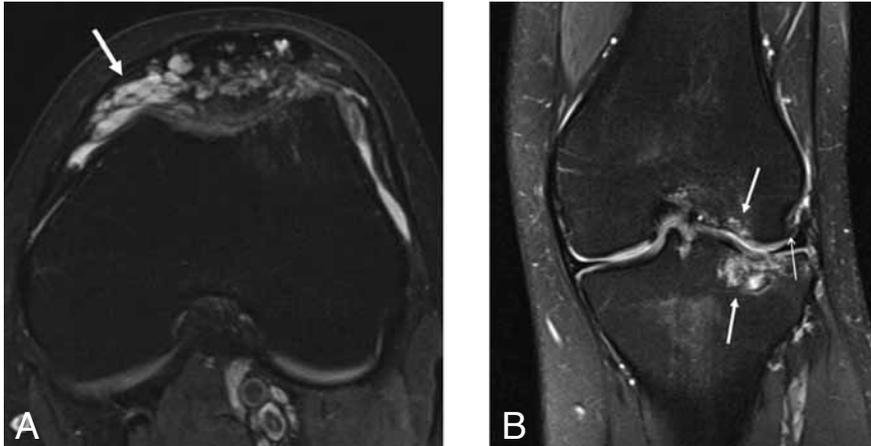
Fig. 9. — Juxtaarticular VM (venous malformation) of the knee in a 17-year-old girl.
A. Axial T2-weighted image with fat saturation demonstrates a small VM (arrow) centred along the anterior aspect of the knee joint, extending into the synovium.
B. Coronal T2-weighted image with fat saturation demonstrates signal changes of the lateral femoral condyle and tibial plateau representing subchondral cyst formation (arrows) and focal bone marrow oedema (arrows). An osteophyte of the lateral femoral condyle is present (thin arrow).

Fig. 10. — Osteonecrosis in a 10-year-old boy.
Sagittal T2-weighted image with fat saturation demonstrates well circumscribed lesions with an interface that appears as a thin, winding line in the epiphysis (arrows) and metaphysis (arrowheads) of the femur and tibia.
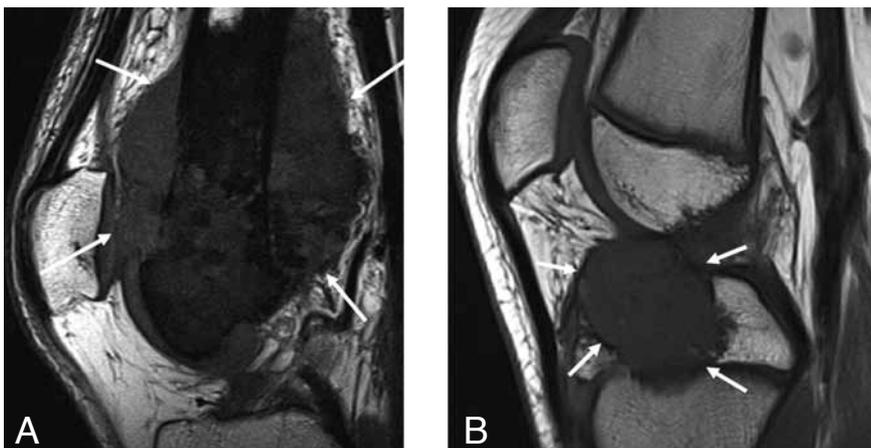

Fig. 11. — Bone tumour of the knee (a) a 15 year-old boy and (b) a 10-year-old boy.
A. Sagittal T1-weighted images demonstrates a large osteosarcoma in the distal femoral diaphysis, metafysis and epiphysis with cortical breach and extraosseous invasion (arrows).
B. Sagittal T1-weighted images demonstrates a large tumour (arrows) in the proximal tibial epiphysis with cortical breach and intraarticular invasion. Diagnosis of enchondroma was confirmed after lesion biopsy.

Early diagnosis of joint haemorrhage and synovial hypertrophy alters the therapeutic management and may prevent progressive joint destruction and surgery (29, 30, 31).

2.2.4. Vascular lesions

Vascular lesions with intraarticular extension may cause osteochondral lesions due to inflammatory response of the synovium and synovial fluid to hemosiderin deposition. The presence of abnormal juxtasynovial vascular structures will suggest the diagnosis (32).

2.2.4.1. Venous malformation (VM)

VM is the most common vascular malformation of the extremities and is clinically blue and compressible. Ultrasound demonstrates venous flow within the lesion. Typical MR imaging findings of VM include cystic or sinusoidal T2 hyperintense structures, presence of phleboliths and central enhancement pattern (32).

There is a high prevalence (nearly 50%) of intra-articular extension of venous malformations (VMs) adjacent to the knee joint, and a strong association of these deep lesions with arthropathy (nearly 90%), often with haemosiderin deposition indicating bleeding into the joint (Fig. 9a-b). The frequency of arthropathy increases with increasing extension of the VM into the joint. MRI evaluation of all juxtaarticular VMs identifies possible associated arthropathy, which may be important in determining the timing and aggressiveness of therapy (32).

2.2.4.2. Synovial haemangioma

Synovial haemangioma presents as a nodular mass lesion. Ultrasound demonstrates arterial flow within the lesion. Within the mass, signal void due to the presence of abnormal vessels may mimic hemosiderin deposits. Intense enhancement of the mass lesion following gadolinium administration with flow voids suggests the diagnosis (33).

2.3. Osteonecrosis

Osteonecrosis of the knee is a frequent complication of high dose steroid treatment of acute leukaemia in children and can lead to joint collapse and may predispose to secondary arthritis (34).

MRI findings of osteonecrosis might be present before any symptoms occur, allowing the earliest and most accurate diagnosis of osteo-
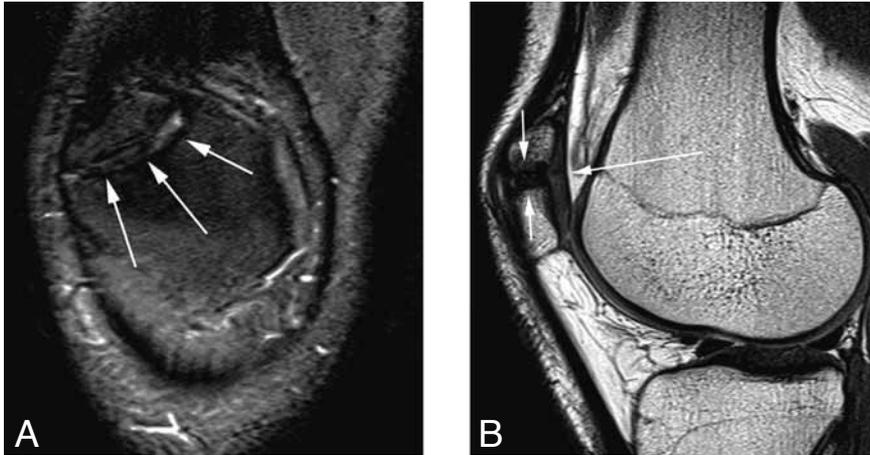
Fig. 12. — Bipartite patella in a 14-year-old girl.
A. Coronal T2-weighted image with fat saturation demonstrates bipartite configuration of the cranial lateral aspect of the patella (arrows).
B. Sagittal Pd-weighted image with fat saturation demonstrates a hypointense lesion in the cranial aspect of the patella (arrows). The retropatellar articular cartilage appears normal (long arrow).

Fig. 13. — Normal ossification variants of the femoral condyle mimicking osteochondral lesion.
A. Sagittal T1-weighted MR image in a 7-year-old girl demonstrates an ill-defined osseous defect (arrow) in the posterior third of the lateral femoral condyle. An ossification completely fills the defect.
B. Sagittal T1-weighted MR image in a 10-year-old boy of the knee demonstrates the presence of extra ossification centres (arrows) in the non-ossified cartilage of the posterior third of the lateral femoral condyle.

necrosis (35). The lesions typically have a geographical appearance with a characteristic interface between living and dead bone at the periphery of the lesion that appears as a thin, winding line with low T1 signal and high T2 signal that circumscribes and clearly demarcates the zone of necrosis (Fig. 10a-b). In case of progression with sub - chondral collapse, which is a complication of progressive osteonecrosis near a joint surface, the inner zone of necrosis may show low signal intensity or might be inhomogeneous (36).

2.4. Tumour

The diagnosis of a bone tumour in children is often delayed and at time of diagnosis intraarticular extension with osteochondral destruction may be present. Enhancing osseous mass lesions with extensive surrounding bone marrow oedema, breach of the cortex with periosteal reaction and extension into the soft tissues fit every definition of malignant tumour (Fig. 11a). However, benign bone tumours may demonstrate extraosseous extension as well (Fig. 11b). Prompt recognition

and biopsy of the tumour is mandatory.

Correlation with age and site of the lesion (eg. epiphyseal, diaphyseal or metaphyseal) may be helpful in the differential diagnosis. Metastasis of neuroblastoma and leukemia have to be included in the differential diagnosis in infants whereas osteosarcoma is the most common malignant primary bone tumour in children and adolescents (36-37).

The most important role of MRI is to image the extend of the primary tumour and to look for skip metastasis. Dynamic contrast-enhanced MRI may be helpful in monitoring response to therapy in osteosarcoma since the active tumoral tissues in size with treatment, whereas lesional volume reduction does indicate response to therapy for Ewing sarcoma (37).

3. Developmental ossification variants

3.1. Bipartite patella (BP) and dorsal patellar defect (DPD)

The patella usually arises from a single ossifying nucleus, but secondary centres of ossification may be located in the supero-lateral quadrant. These usually fuse to form a single bone, but may remain separate to form a bipartite or multipartite patella (Fig. 12a-b). The dorsal patellar defect is also thought to represent a failure in the ossification of the patella (38-40).

Skeletal normal variants may become symptomatic after repetitive stress: painful bipartite patella is related to the effects of traction forces in the fibrocartilaginous synchondrosis (37). Most DPD remain asypmtomatic as the cortical defect is usually compensated by overgrowing articular cartilage (40).

3.2. Ossification variants of the femoral condyle

Normal variants of ossification are common in rapidly growing children and should not be confused with lesions (16, 17). Ossification defects in the posterior femoral condyles with intact overlying cartilage, accessory ossification centres, spiculation, greater residual physeal cartilage and lack of bone marrow oedema are features of developmental variants (17). Sample images of ossification variant are presented in Fig. 13 a-b. Early ossification centre in the residual cartilage is the most common ossification variant, followed by spiculated configuration of

the secondary ossification centre, pre-ossification centre, extra ossification centre, puzzle piece and incomplete puzzle piece configuration ossification variant (17).

Conclusion

Lesions of the knee become increasingly more common in children. MRI clearly depicts osteochondral lesions of the paediatric knee and can differentiate traumatic from non traumatic knee lesions. Recognition of these conditions is mandatory since timely diagnosis guides therapy and may prevent lifelong disabilties. Normal ossification variants may occur in the ossifying knee and can mimic lesions.

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