The pediatric knee: Beyond traumatic injuries

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Learning objectives

-To remember the anatomy of the knee in the pediatric age.

-To review the bone maturation process and its normal appearance.

-To describe diverse non-traumatic entities that can affect the knee, with special interest in magnetic resonance (MRI) findings.
Background

knee pain in children is a common reason to seek medical attention. Imaging findings of the pediatric Knee differ from those found in adults, due to the process of skeletal maturation and the diversity of pathologies that affect this age range.

Based on a wide variety of cases collected in our center, we describe how to recognize common pediatric developmental variants and specific findings of congenital, inflammatory, infectious and neoplastic conditions.
Findings and procedure details

NORMAL SKELETAL MATURATION

The epiphyses, at the distal ends of the tubular bones, are located between the primary physis (growth plate) and the joint. Initially, the epiphysis is formed entirely by cartilage, inside which, the secondary ossification center will appear Fig. 1 on page 10 [1].

At birth hematopoietic bone marrow (BM) is present throughout the entire skeleton. The hematopoietic BM shows low signal intensity in the T1-weighted sequences and high signal intensity in the T2-weighted sequences (less than the fluid and similar to the muscle). During the first year of life, hematopoietic marrow begins the conversion to fatty marrow, starting in the epiphysis and progressing towards the metaphysis [1] Fig. 2 on page 10.

In the knee of young adults, hematopoietic BM might remain adjacent to the physis Fig. 3 on page 11. The fat conversion of hematopoietic BM in patients with anemia or who receive growth factors occurs in the opposite direction (metaphysis-diaphysis-epiphysis) [1,3] Fig. 4 on page 12.

BM malignant infiltration will cause a signal intensity decrease in T1-weighted images, lower than the muscle signal intensity[1,3] Fig. 5 on page 13.

NORMAL VARIANTS ON THE PEDIATRIC KNEE

1. OSSIFICATION VARIANTS OF THE DISTAL FEMORAL EPIPHYSIS

Femoral condyle ossification may be irregular, showing in the radiography the presence of a radiolucent image located in the distal femoral epiphysis. It may be bilateral, and it usually involves the posterior part of the lateral condyle, although it may sometimes affect the medial condyle or both Fig. 6 on page 14 Fig. 7 on page 15. Main differential diagnosis includes the osteochondral lesion, which usually appears in the medial region of the internal condyle and it is associated with bone marrow edema [2,3,4] Fig. 8 on page 16.

2. DISTAL FEMORAL CORTICAL IRREGULARITY OR CORTICAL DESMOID

It is a benign fibrous lesion located in the posterior region of the distal metaphysis of the femur, in the insertion of the internal gastroctemius muscle. It appears in the radiography
as a radiolucent lesion, with a sclerotic border Fig. 9 on page 17. MRI images show a hypointense lesion in T1-weighted sequences, with intermediate signal intensity in T2-weighted sequences and a hypointense border in all sequences [2, 3] Fig. 10 on page 18

3. POSTERIOR METAPHYSEAL STRIPE

Subperiosteal stripe in the posterior region of the distal femoral metaphysis, hyperintense in T2-weighted sequences, secondary to the presence of subperiosteal fibrovascular tissue in the pediatric age Fig. 11 on page 19

4. IRREGULARITY OF THE TIBIAL TUBEROSITY

The ossification of the anterior tibial tuberosity may be irregular and fragmented. In contrast to Osgood-Schlatter disease, this normal variant is usually painless and pretibial soft tissue increased is not seen.[5] Fig. 12 on page 20 Fig. 13 on page 20

5. PATELLA OSSIFICATION VARIANTS

The patella is usually formed from 2 or 3 ossification centers. The bipartite patella is the most common ossification variant, an unfused ossification center at the superolateral aspect [3,5,6,7] Fig. 14 on page 21.

Occasionally, ossification of the normal patella may appear granular or nodular, with radiolucent and sclerotic areas [3,5,6,7] Fig. 15 on page 22 Fig. 16 on page 23 Fig. 17 on page 24

The dorsal defect of the patella is a variant, of unknown etiology, in which the appearance of a radiolucent image with a sclerotic border on the superolateral border of the patella is evident, without bone marrow edema or cartilage involvement, which should not be confused with an osteochondral fracture [3,5,6,7] Fig. 18 on page 25.

DEVELOPMENTAL DISORDERS

1. CONGENITAL ABSENCE OF CRUCIATE LIGAMENTS

This is a very infrequent finding. They are usually associated with other malformations, such as longitudinal limb deficiencies. MRI usually shows an abnormal morphology of the tibial spines, dysplastic femoral condyles, and absence of cruciate ligaments, with hypertrophy of Humphrey’s meniscofemoral ligament. [3,9] Fig. 19 on page 26.
2. DISCOID MENISCUS

Dysplastic and enlarged meniscus, with loss of the normal semilunar morphology. It is usually more frequent on the external side. It may be identified in the MRI sagittal sequences, in which continuity of the anterior and posterior horn will be seen in three or more cuts. Signs of mucinous degeneration use to be found and there is a greater probability of tears [3,8] Fig. 20 on page 27.

3. BLOUNT DISEASE

Blount disease refers to a local disturbance of growth of the medial aspect of the proximal tibial metaphysis and/or epiphysis that results in tibia vara. The medial epiphysis is wedge-shaped and the adjacent metaphysis is fragmented and depressed, with physis bone bars. The medial meniscus usually presents associated degenerative changes [6] Fig. 21 on page 28 Fig. 22 on page 29.

4. VASCULAR MALFORMATIONS

Vascular malformations can affect the bone, synovium or extra-articular soft tissues, although the majority presents intraarticular location. These malformations are present at birth and grow with the child. Main symptoms are pain, swelling, and spontaneous hemarthroses.

The intra-articular lesions can be low-flow (venous, lymphatic, capillary or mixed) or high-flow vascular malformations (malformations and arteriovenous fistulas). Synovial venous malformations are the most frequent in the knee. They are usually visualized in MRI as a lobulated multiloculated mass, with venous lakes separated by septa. It shows intermediate signal intensity in T1-weighted sequences and hyperintense in T2-weighted sequences, with signal voids secondary to phleboliths and heterogeneous uptake of contrast due to thrombi [3, 10,11] Fig. 23 on page 30.

INFECTIOUS DISEASES

Osteomyelitis is a bone infection that frequently affects the growing skeleton, with half of the cases occurring in children under the age of 5. It is usually secondary to bacterial hematogenous spread (S. aureus). [12].

It usually affects the metaphysis of the tubular bones. Epiphysis might be affected in children up to 2 years of age. Osteomyelitis is classically divided into acute, subacute
and chronic, depending on the clinical features, the duration of the disease and imaging findings.

1. ACUTE OSTEOMYELITIS:

The x-ray imaging is usually normal during the first days[18]. MRI shows the edema in the BM and adjacent soft tissues. The lesion shows a heterogeneous contrast-enhancement with areas of ischemia secondary to an increase in intramedullary pressure, vascular thrombosis, and interruption of the blood supply of the periosteum. It is common the appearance of intraosseous and subperiosteal abscesses, which can cross the cortical bone, with purulent material that may drain to soft tissue [18] Fig. 24 on page 32 Fig. 25 on page 31 Fig. 26 on page 33.

2. SUBACUTE OSTEOMYELITIS:

It is characterized by the appearance of the Brodie's abscess. In the radiography, it will be visualized as a well-circumscribed lytic lesion with sclerotic borders. MRI shows a center of necrosis, surrounded by a ring of granulation tissue that has an intermediate intensity in T1-weighted MRI image ("the penumbra sign") [12] Fig. 27 on page 33.

3. CHRONIC OSTEOMYELITIS:

It is characteristic the appearance of fragments of necrotic bone (sequestrum), surrounded by purulent tissue and reactive bone sclerosis (involucrum). A defect in the cortical bone can also develop, allowing drainage of the purulent material into adjacent soft tissue or skin (sinus tract) Fig. 28 on page 34.

INFLAMMATORY DISEASE

1. PIGMENTED VILLONODULAR SYNOVITIS

Benign proliferative disease of unknown etiology. The knee is the most involved joint. It is rare in the pediatric age. MRI demonstrates a lobulated mass (synovial proliferation). Lesions tend to bleed, causing hemosiderin deposition and therefore a low-intensity signal in all sequences. There may be areas of hyperintensity in T2-weighted sequences due to synovial inflammation and joint effusion. In the knee, associated bone erosion is infrequent [11, 13] Fig. 29 on page 35.
2. JUVENILE INFLAMMATORY ARTHRITIS

Chronic rheumatological disease, more frequent in children under 16 years. The most frequent form of presentation is the oligoarticular, with greater involvement of the knee. On MRI the most frequent findings are [11, 13] Fig. 30 on page 36 Fig. 31 on page 37.

- Joint effusion with thickening and synovial enhancement.
- Inflammatory pannus (mass-like synovial proliferation, with heterogeneous enhancement).
- Hoffa’s fat-pad inflammation.
- Intraarticular low-signal loose bodies (rice bodies).
- Bone erosions (chronic changes).

3. LIPOMA ARBORESCENS

Infrequent benign synovial lesion of unknown etiology, characterized by a massive infiltration of the synovium by mature adipocytes without atypia. The most frequent form is the monoarticular involvement of the knee. MRI is characterized by the presence of joint effusion (with frequent synovial contrast-enhancement) and multiple synovial proliferation of adipose tissue (“rice grains”). Occasionally, it may show the aspect of a soft tissue mass with fat signal characteristics [11,17] Fig. 32 on page 38.

NEOPLASTIC PATHOLOGY

1. FIBROUS CORTICAL DEFECT (FCD) & NONOSSIFYING FIBROMA (NOF)

It is a frequent benign neoplasm. It is usually found in metaphyses. It appears as a lytic lesion with well-defined sclerotic borders. As the lesion matures, sclerosis increases. MRI imaging features depend on the degree of maturation of the lesion [3] Fig. 13 on page 20 Fig. 14 on page 21 Fig. 33 on page 39.

2. OSTEOCHONDROMA

This is the second most frequent benign pediatric tumor. They usually appear in the metaphysis of long bones, especially the distal femur and proximal tibia. It is an extension
of bone that shows continuity with the periosteum, cortex, and bone marrow of the native bone. It presents a cartilaginous cap that will be visualized as an intermediate signal intensity in T1-weighted sequences and high in T2-weighted sequences. It is usually asymptomatic, except in complications: compression of nerves or vessels, fracture, inflammation of the exostosis bursa. Malignant transformation is rare (<1%) [3,16] Fig. 34 on page 40 Fig. 35 on page 41.

3. CHONDROBLASTOMA

It is a rare benign tumor of immature cartilage, with a peak incidence between 10 and 20 years. It has a predilection for the epiphysis of the femur and tibia. They often pass through the physis to the adjacent metaphysis or even the joint. X-ray is shown as a radiolucent lesion with sclerotic borders and a chondroid matrix inside. MRI shows a heterogeneous lobular pattern, with a low-intermediate signal intensity in T1-weighted sequences and variable in T2-weighted sequences, with a peripheral hypointense ring. 60% of the cases show variable contrast enhancement. An accompanying periosteal reaction can be observed, as well as edema of the bone marrow and the surrounding soft tissues [3] Fig. 36 on page 42.

MALIGNANT TUMOURS

1. OSTEOSARCOMA

Osteosarcoma is the most common primary malignant tumor of the knee. They usually appear in the metaphysis of long bones (most frequent in the femur) and it may extend to the epiphysis. The x-ray will show a lesion with aggressive features, permeative appearance, with cortical destruction, soft tissue mass and aggressive periosteal reaction. In MRI it usually appears hypointense in T1-weighted sequences and hyperintense in T2-weighted sequences with foci of low intensity in all sequences, secondary to its osteoid matrix [3,5]. At least one entire bone sequence must be performed to exclude other lesions (up to 15%) Fig. 37 on page 43 Fig. 38 on page 44 Fig. 39 on page 45.

2. EWING SARCOMA

It is the second primary malignant tumor of childhood. Imaging typically demonstrates an aggressive lesion, similar to osteosarcoma. In contrast, it usually associates an important non-calcified soft tissue mass. Fig. 40 on page 46.
Fig. 1: Sagittal T2*-weighted gradient-echo MR image. Epiphysis: Epiphyseal cartilage (arrowhead) and secondary ossification center (red arrow). Primary physis (blue arrow).

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Fig. 2: (A) Sagittal FSE T1-weighted and (B) STIR MR images in a 7-month-old child. Hematopoietic bone marrow in the distal diaphysis of the femur, proximal to the tibia and both metaphyses. Fatty bone marrow in both epiphyses.

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**Fig. 3:** 13-years-old girl. Coronal FSE T1-weighted(A) and sagittal STIR(B) MR images. Rests of hematopoietic BM in the tibial metaphyses.

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Fig. 4: Coronal FSE T1-weighted (A) and sagittal STIR (B) MR images. 14-years-old boy with cubital Ewing sarcoma and bone metastasis (arrows). Conversion of fat BM to hematopoietic BM in femoral and tibial metaphyses.

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Fig. 5: PA and lateral radiograph (A and B), Sagittal FSE T1-weighted (C), Coronal T2*-weighted gradient-echo(D). 2-years-old girl with acute lymphoid leukemia and BM diffuse infiltration. Permeative lesion in tibial diaphysis, with aggressive periostic reaction (Codman triangle) and pretibial soft tissue mass.

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**Fig. 6:** Ossification variant. PA (A) and lateral (B) radiograph, where a radiolucent image is observed in the posterior part of the external femoral condyle (red arrows). Sagittal CT (C) and 3D reconstruction (D), where multiple bone fragments are observed in the external femoral condyle (blue arrows).

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Fig. 7: Sagittal proton-density-weighted (A), proton-density-weighted FS (B) and T2*-weighted gradient-echo(C) MR images, showing bone fragments separated from the rest of the femoral epiphysis by cartilage, without the presence of bone marrow edema (yellow arrows).

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Fig. 8: 13-year-old boy with right knee pain. PA (A) and intercondylar knee radiograph (B). Radiolucent image in internal femoral condyle (arrow) and small intraarticular foreign body in the internal compartment (arrowhead). Coronal FSE T1-weighted (C) and STIR (D) MRI images, showing an osteochondral lesion, with signs of instability, medial margin of the internal femoral condyle, with associated bone marrow edema.

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Fig. 9: Lateral knee radiography. Radiolucent image with sclerotic border (arrow).

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**Fig. 10:** Sagittal FSE T1-weighted(A) and sagittal FS proton-density-weighted(B). Distal femoral cortical irregularity (arrows).

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**Fig. 11:** Sagittal T2*-weighted gradient-echo (A) and axial FS proton-density-weighted(B). Distal femoral cortical irregularity (arrows).
Fig. 12: Lateral knee radiograph(A) and Sagittal proton-density-weighted MRI(B). Fragmentation of the anterior tibial tuberosity (arrows), without pretibial soft tissue increase.
Fig. 13: Lateral knee radiograph (A) and sagittal CT image (B). Fragmentation of the anterior tibial tuberosity, with pretibial soft tissue increase, in relation to Osgood-Schlatter disease. Cortical fibrous fibular defect (arrow).

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**Fig. 14:** PA and lateral knee radiograph. Bipartite patella. Non-ossifying femoral fibroma (arrows).

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**Fig. 15:** Lateral, PA and axial radiographs of knees. Irregular ossification of both patellae.

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Fig. 16: Variant of patellar ossification. Lateral and PA knees radiographs. Sagittal CT and 3D reconstruction. Sagittal proton-density-weighted and Coronal FSE T1-weighted MRI.

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**Fig. 17:** Radiological control 6 months later. Patella ossified homogeneously.

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**Fig. 18**: Patellar dorsal defect. (A) Lateral and axial radiographs (B) Axial and sagittal CT reconstructions. Axial FS proton-density-weighted (C), sagittal and axial T2*-weighted gradient-echo MR images. (D and E).

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Fig. 19: Patient with longitudinal fibular deficiency (fibular hemimelia) (A), absence of both cruciate ligaments (C, D) and hypoplasia of femoral condyles (B). Radiograph at one year of age (A). Axial proton-density-weighted FS (B) Sagittal proton-density-weighted (C) and coronal FSE T1-weighted(D) at 5 years of age.

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Fig. 20: External discoid meniscus with marked degenerative changes and complex tear in the body and anterior horn. A) Sagittal FSE T1-weighted, B) Sagittal FS proton-density-weighted, C) Coronal proton-density-weighted, D) Coronal STIR MR images.

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Fig. 21: Blount disease. (A) PA radiograph, (B) Coronal T2*-weighted gradient-echo and (C) Coronal FSE T1-weighted MR images. Inclination and medial fragmentation of the epiphysis, with the formation of bony bridges and metaphyseal widening (arrows).

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Fig. 22: Advanced Blount disease. Coronal CT(A), T1-weighted(B) and T2*-weighted gradient-echo MR image(C).

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Fig. 23: Venous malformation in the internal articular recess that infiltrates the anterior margin of the right femoral condyle, the vastus medialis, and the patellar retinaculum. A) Sagittal STIR, B) Axial FSE T2-weighted, (C and D) Coronal and axial contrast-enhanced fat-suppressed T1-weighted, (E) Dynamic angio-MRI.

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Fig. 25: Sagittal and axial contrast-enhanced fat-suppressed T1-weighted MRI. Femoral acute osteomyelitis with septic arthritis, soft tissues edema and small posterior subperiosteal collection (arrow).

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**Fig. 24:** Coronal and axial Contrast-enhanced fat-suppressed T1-weighted MRI. Tibial acute osteomyelitis with an extensive area of ischemia. Myositis signs with small intramuscular abscesses (red arrows) and subperiosteal abscess (blue arrow).

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**Fig. 26:** A) Axial contrast-enhanced fat-suppressed T1-weighted, B) Axial FS T2-weighted, C) Sagittal contrast-enhanced fat-suppressed T1-weighted. Patellar acute osteomyelitis. Intraosseous abscess that drains to soft tissues (red arrow). It extends along the patellar tendon (blue arrow). Marked soft tissue edema.

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**Fig. 27:** Subacute OM in a 10-months-old boy. On the radiography, we can see a lytic lesion with sclerotic margins and periosteal reaction (arrow) in femoral metaphysis (A, B). MRI with a metaphyseal abscess that crosses the physis to the epiphyseal cartilage. There is also an extension of the process towards the subperiosteal space. Joint efussion. Coronal FSE T1-weighted(C), coronal STIR(D), sagittal FS T2-weighted (E) and coronal Contrast-enhanced fat-suppressed T1-weighted MR images (F).

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**Fig. 28:** Chronic osteomyelitis in an 8-years-old child. Initial PA radiograph of the tibia and fibula. CT after sequestrectomy, cement placement, and fasciocutaneous graft. Extensive metaphyseal-diaphyseal involvement of the right tibia and fibula. Sequestrum (radiograph) and reactive bone sclerosis (involucrum).

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Fig. 29: 14 years old boy with pigmented villonodular synovitis. Ultrasound (A), MRI axial FSE T2-weighted (B), sagittal Contrast-enhanced fat-suppressed T1-weighted(C), sagittal T2*-weighted gradient-echo(D).

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**Fig. 30:** 10-year-old boy with an oligoarticular form of JIA. Sagittal contrast-enhanced fat-suppressed T1-weighted MRI and CT. Joint effusion with thickening and synovial uptake. Inflammatory changes in Hoffa’s fat-pad. Erosion in the posteromedial margin of the internal tibial plateau.

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**Fig. 31:** 2-year-old girl with an oligoarticular form of juvenile inflammatory arthritis. Joint effusion with marked thickening and diffuse enhancement of the synovium. A) Ultrasound, B) Axial T2-weighted, C) Axial FS T2-weighted and D) Axial contrast-enhanced fat-suppressed T1-weighted MR images.

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**Fig. 32:** 12-year-old girl with an arborescent lipoma. Synovial fatty tissue proliferation. A) Axial T2-weighted, B) Axial Contrast-enhanced fat-suppressed T1-weighted, C) Coronal T1-weighted and D) Coronal FS proton-density-weighted MR images, E) Ultrasound.

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Fig. 33: NOF in the proximal diaphysis of the fibula. PA and lateral knee radiograph (A, B). Coronal FSE T1-weighted and coronal STIR.

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Fig. 34: Osteochondroma. Coronal T1-weighted and axial T2-weighted MR images.

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**Fig. 35:** 14-year-old girl with multiple osteochondromatosis and intense pain in the popliteal fossa. Osteochondroma (arrowhead), with a bursa complicated by bleeding (between red arrows) and secondary popliteal venous thrombosis secondary to compression (yellow arrow). 3D CT reconstruction (A), ultrasound cross-section (B), MRI axial T1 (C), cross-section of popliteal vein and artery (D).

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**Fig. 36:** Chondroblastoma in the epiphysis of the internal femoral condyle. PA and lateral radiograph (A, B), Coronal CT (C), Sagittal T1-weighted (D), axial T2-weighted (E) and coronal STIR MR images(F).

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Fig. 37: AP and lateral radiograph, and sagittal CT. A 7-year-old boy with a history of bilateral retinoblastoma. Osteosarcoma in the distal femur.

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Fig. 38: Lateral knee radiograph (A), coronal (B) and axial CT (C y D) show an osteosarcoma located in the distal metaphysis of the femur with large soft tissue mass and agressive periosteal reaction. Axial FS T2-weighted MRI(E): The soft tissue mass has a cystic component with fluid levels that suggest intralesional bleeding. Coronal contrast-enhanced fat-suppressed T1-weighted (F), the lesion extends upwards to proximal metaphysodiaphyseal junction.

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**Fig. 39:** Coronal T2-weighted (A), sagittal T1-weighted (B) and contrast-enhanced fat-suppressed T1-weighted MR images (C). Tibial metaphysis osteosarcoma with physeal extension and accompanying soft tissue mass.

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**Fig. 40:** Ewing's sarcoma in the fibula. X-ray (A), CT (B), MRI sagittal STIR (C), coronal T1 FS with contrast (D) and coronal T1 (E).

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Conclusion

The pediatric knee joint disorders are frequent. The knowledge of the developmental variants and frequent pathological conditions in the pediatric knee is important to accurate the diagnosis.
References


