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MR IMAGING OF THE PEDIATRIC KNEE

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A variety of imaging techniques is now available to investigate the growing knee. MRI, however, is playing an increasing role in the evaluation of bone, cartilage, joint space, tendon, soft tissue inflammation and other abnormalities in children’s and adolescents’ knees. MRI has become especially useful in the assessment of disorders of growing knee joints with the recent publications on normal age-related variation in MR imaging signal intensity within the cartilaginous epiphysis of the distal femur [1] and proximal tibia and fibula [2, 3].

The spectrum of pediatric knee disorders ranges from traumatic derangement, osteochondritis / osteonecrosis, rheumatic diseases, infection / inflammation to tumors. We discuss the ethopathogenesis and MRI findings that characterize these various diseases affecting the knee region of children and adolescent and summarize recent MRI techniques developed for early detection of morphologic and functional disorders of the knee.

TRAUMATIC DERANGEMENT / OSTEOCHONDritis / OSTONECROSIS

Conventional MRI (T1-weighted, T2-weighted spin-echo/fast- spin-echo and gradient-echo sequences) has proven to be valuable in evaluating fractures of the distal femur and proximal tibia in children and adolescents [4, 5]. It can detect abnormalities in the cartilage that are associated with subsequent growth disturbances and provides accurate mapping of physeal bridging and associated growth abnormalities that have already occurred. Whereas providing improved delineation of non-displaced physeal fractures of the knee compared to conventional radiography, it simultaneously allow for evaluation of soft tissue structures [5].

With regard to injuries to the extensor mechanism of the knee, MRI is able to clearly demonstrate imaging characteristics of quadriceps muscle injury, patellar sleeve fracture, patellar dislocation, and patellar tendon injury with development of osteochondritis (either at the proximal region of the tendon, Sinding-Larsen-Johansson syndrome, or at the insertion of the patellar tendon at the tibial tuberosity, Osgood-Schlatter disease) [6].

The mechanism of injury of the quadriceps muscle involves placing stress on the quadriceps group with the knee flexed. In young healthy patients this injury occurs by strong deceleration as when someone is running and his/her leading foot is planted [6]. This musculotendinous unit is most often injured within 2 cm of the upper margin of the patella [7].

Patellar sleeve fracture is an acute cartilaginous avulsion from the lower pole of the patella occurring during forceful contraction of the quadriceps muscle against a partially flexed knee [8].

Acute patellar dislocations are common injuries in children, accounting for approximately 9-16% of acute trauma in young athletes with hemarthrosis [9]. In acute dislocation, there is complete, lateral displacement of the patella from the femoral trochlear groove. MR imaging can detect occult traumatic patellar dislocation by the identification of a constellation of indirect signs of injury: hemarthrosis, osteochondral injury, bone bruising of the medial patellar facet and lateral femoral condyle, and soft tissue damage to the medial retinaculum and medial patellofemoral ligament [10].

Sinding-Larsen-Johansson syndrome (children’s equivalent of patellar tendinitis or “jumper’s knee”) refers to a chronic insertional tendinopathy seen in skeletally mature athletes in...
which a traction apophysitis is noted in the inferior patellar pole. This injury is due to repeated stress or vigorous exercise, and is more prevalent in boys [11].

Osgood-Schlatter disease is a chronic traction apophysitis of the tibial tubercle caused by repetitive traction trauma to the apophysis with a resulting tender prominence of the tibial tubercle [11]. Typically, both Sinding-Larsen-Johansson syndrome and Osgood-Schlatter disease adequately resolve by skeletal maturity without any need for surgery.

Patellofemoral pain syndrome (chondromalacia patellae, “runner’s knee”) is a condition characterized by softening, fraying, and ulceration of patellar articular cartilage, that results from poor alignment of the patella as it slides over the distal femur [12, 13]. Patients with chondromalacia patellae frequently have abnormal patellar "tracking" toward the lateral aspect of the femur. This slightly-off-kilter pathway allows the undersurface of the patella to grate along the femur causing chronic inflammation and pain. Certain individuals are predisposed to develop chondromalacia patellae: females, knock-kneed or flat-footed runners, and those with an unusually shaped patella undersurface [14]. Previous studies demonstrated that spectral presaturation with inversion recovery (SPIR) sequences are superior to magnetization transfer contrast (MTC) sequences in the identification of low grade lesions in the patellar cartilage [15].

Osteochondritis dissecans (OCD) is the most common cause of a loose body in the joint space in adolescent patients [16]. In spite of the better prognosis of juvenile osteochondritis dissecans in comparison to the adult type [17], this entity may potentially lead growing joints to collapse and may predispose them to secondary arthritis. Note is made that grade I OCD (subchondral bone defect without articular cartilage interruption) can be confused with variants of ossification during normal development of the knee [17].

Osteonecrosis of the knee is a frequent complication of treatment of leukemia and lymphoma in children [18]. The most typical feature of the early osteonecrosis lesion is the characteristic interface between living and dead bone at the lesion’s periphery which is readily visible without the use of a contrast agent. In early MR-evident osteonecrosis, radiographs are often normal.

In the immature skeleton, the medial meniscus is injured more frequently than the lateral meniscus or the anterior cruciate ligament (ACL) [19]. Initial studies on the overall diagnostic performance of conventional MR imaging (proton-density weighted, T2-weighted and T1-weighted spin-echo imaging) for assessment of meniscal tears reported values of sensitivity and specificity of 83% and 95%, respectively, in children [19], and of 74% and 95%, respectively, in adults [20]. The majority of meniscal tears in children under the age of 10 years are due to a lateral discoid meniscus. Discoid meniscus is an abnormality of the fibrocartilaginous meniscus of the knee in which the meniscus is discoid rather than semilunar in shape [21].

With relation to anterior cruciate ligament (ACL) injuries, the sensitivity and specificity of conventional MR imaging for evaluation of ACL tears in pediatric knees are 95% and 88%, respectively [22]. Tibial avulsion fractures and partial tears are more common in younger, less rigid skeletons that may absorb the forces of trauma. As children’s joints mature, complete ACL tears and associated injuries occur in frequencies approaching those patterns seen in adults [23].

RHEUMATIC DISEASES

Juvenile idiopathic arthritis (JIA) is the most common rheumatic disorder of childhood [24]. Conventional MR imaging at 1.5 Tesla is able to detect synovial hypertrophy and joint effusions in early disease (<1 year of duration). Preliminary studies [25] showed that fast spin-echo intermediate-weighted and 3D spoiled gradient recalled (SPGR) imaging can identify early cartilage damage (signal intensity heterogeneity in the patellar cartilage, subchondral cartilage fissures at the patella, and femoral and tibial cartilage thinning) in approximately 10% of the
radiographically occult cases. Baker’s cysts may be associated with inflammatory arthritis or cartilage tears. They demonstrate fluid extending between the medial head of the gastrocnemius muscle and the tendon of the semimembranosus muscle into a distended bursa [26].

Differential diagnostic considerations for synovial abnormalities of the pediatric knee include hemophilia, lipoma arborescens, nodular synovitis, synovial hemangioma, chondroma, pigmented villonodular synovitis, foreign body, septic arthritis and Klippel-Trenaunay syndrome, in addition to JIA. With specific regard to hemophilic arthropathy, multiplanar gradient recalled (MPGR) MR images are able to clearly demonstrate deposition of hemosiderin components resultant from previous bleeding episodes in hemophiliacs along the capsular and cartilage surface of the joint. The intravenous administration of gadolinium DTPA-chelates better delineates the extent of synovial thickening and enhancement which represent different degrees of synovial inflammation [27].

**INFECTION / INFLAMMATION**

Certain aspects of pediatric osteomyelitis pose unique diagnostic challenges. Infections in neonates and infants are initially clinically silent. Young children may present with only limping and refusal to bear weight [28]. The metaphysis is usually the site of hematogenous seeding, due to sluggish flow in the sinusoidal vessels and decreased phagocytic activity. The metaphysis of children is difficult to evaluate both scintigraphically and by MR imaging [29]. Nevertheless, early detection and treatment of osteomyelitis can prevent sepsis and chronic infection and can minimize sequelae such as growth arrest [30].

One proposed approach for imaging assessment of osteomyelitis in children [28] recommends that plain radiographs should be obtained in every patient with suspected osteomyelitis. In most cases, this should be followed by skeletal scintigraphy. MR imaging should be done in scenarios that may require surgical drainage, including infections of the spine or pelvis, infections extending into the physes of long bones, and infections that fail to respond to antibiotics.

Chronic recurrent multifocal osteomyelitis (CRMO) is a well-established skeletal disorder of unknown etiology mainly occurring in children and adolescents [31]. This clinical entity is a diagnosis of exclusion, distinct from bacterial osteomyelitis, based on the following criteria: (1) bone lesions with a radiographic picture suggesting subacute or chronic osteomyelitis; (2) an unusual location of lesions when compared with infectious osteomyelitis with a frequent multifocality; (3) no abscess formation, fistula or sequestra; (4) lack of a causative organism; (5) nonspecific histopathological and laboratory findings compatible with subacute or chronic osteomyelitis; (6) a characteristic prolonged, fluctuating course with recurrent episodes of pain; (7) occasional accompanying skin disease. The lesions of CRMO are predominantly located on tubular bones including the distal femoral metaphyses [32] followed by the clavicle, the spine and pelvic bones [33].

When the infection reaches the joint, septic arthritis takes place. Due to the anatomy and blood supply in neonates, osteomyelitis often co-exists with septic arthritis [34]. In septic arthritis bacterial contamination causes hypertrophy and edema of the synovium. In infants with septic arthritis distension of the joint capsule may result in pathologic dislocation. Joint space narrowing results from cartilage destruction by proteolytic enzymes. There may be associated bone erosion and destruction or periosteal reaction. Pus in the joint increases intraarticular pressure and may result in osteonecrosis of the epiphysis [35]. Other sequelae include angular deformities, leg length discrepancy and ankylosis. Early radiographic findings of joint effusion may be detected in the knee, ankle or elbow but radiographs are insensitive for detecting effusion.
in the joints [36]. MRI is sensitive in demonstrating joint effusion but cannot distinguish infected from non-infected joint effusion and aspiration is still necessary for diagnosis. MR imaging may be used to demonstrate early bone erosions and cartilage destruction. In addition to joint effusions, associated findings include synovial thickening and enhancement, septations and debris within the joint [37]. Uncomplicated septic arthritis may cause abnormal signal within the bone marrow on both sides of the joint secondary to reactive edema which may be difficult to differentiate from osteomyelitis [37]. A secondary complication of septic arthritis includes soft tissue abscess, which demonstrates localized fluid collection with peripheral enhancement following gadolinium enhancement.

TUMORS

Musculoskeletal tumors may originally mimic a traumatic condition of the knee in 3.7% of the cases, and on the basis of an erroneous diagnosis of an athletic injury, an invasive procedure may be performed [38].

According to the site of long bone involvement, epiphyseal tumors include chondroblastoma, intraosseous ganglion cyst, and giant cell tumor. Chondroblastoma is a rare tumor seen in children and adolescents with open growth plates. Giant cell tumor (GCT) is the most common tumor of epiphyses in skeletally mature individuals with closed growth plates. GCT often shows metaphyseal extension. Osteoblastoma, enchondroma, fibrous dysplasia, chondromyxoid fibroma, intraosseous lipoma, simple bone cyst and aneurysmal bone cyst are intramedullary lesions commonly centered in the metaphysis. Non-ossifying fibroma is a metaphyseal lesion centered in the cortex. Osteochondromas are metaphyseal exostoses. Ewing’s sarcoma, osteosarcoma, and lymphoma typically arise in the metaphysis and diaphysis of long bones as intramedullary lesions and may extend secondarily into the epiphysis. Adamantinoma and osteoid osteoma are diaphyseal lesions centered in the cortex [39].

Within the soft tissues, lesions of fluid intensity include parameniscal cysts, which are associated with meniscal tears, and ganglion cysts, which have an uncertain etiopathogenesis. Non-fluid based lesions include hematomas whose signal on T2-weighted images varies with the age of the blood products, pigmented villonodular synovitis, intracapsular chondromas, and synovial sarcomas. The differentiation between the two latter entities may be difficult or impossible. Malignant soft tissue tumors are usually of isointensity or low signal intensity relative to skeletal muscle and high signal intensity on T2-weighted images, and are often heterogeneous in signal [26].

NOVEL CLINICAL AND EXPERIMENTAL MRI TECHNIQUES FOR ASSESSMENT OF INTERNAL STRUCTURES OF THE PEDIATRIC KNEE

The anatomic MRI sequences that have shown to be accurate in the detection of articular cartilage diseases include fat-suppressed three-dimensional spoiled gradient-recalled (SPGR) images acquired in the steady state [40, 41] and T2-weighted fast spin-echo (FSE) images [42-44].

Driven equilibrium Fourier transform (DEFT) imaging has been shown to provide high contrast between cartilage and synovial fluid without loss of cartilage signal [45]. Small cartilage surface irregularities and fissures have been best delineated with the DEFT sequence when compared with the SPGR and FSE sequences. The usefulness of these sequences appears more related to their high sensitivity and negative predictive values for detection of cartilage abnormalities [46].
Fluctuating equilibrium MR (FEMR) imaging is a variant of steady-state free precession (SSFP) imaging that may be useful in imaging cartilage in the knee [47]. Another similar approach that may provide more reliable fat suppression at high resolution is Dixon SSFP imaging [48]. This technique is faster and can provide more reliable fat suppression than fat-suppressed 3D spoiled GRE imaging.

Within the domain of functional MRI for assessment of articular cartilage, the sensitivity of MR imaging to biochemical and biophysical changes in the extracellular matrix of articular cartilage gives it the potential to noninvasively detect the earliest changes of cartilage damage [49]. The transverse relaxation time (T2) of cartilage has been shown to be a sensitive parameter for evaluation of early degeneration in articular cartilage in children’s knees, particularly changes in water and collagen content and tissue anisotropy [50].

Sodium MR imaging has recently shown promising results in the imaging of articular cartilage based on its ability to depict regions of glycosaminoglycan depletion [51, 52].

Diffusion-weighted imaging (DWI) probes abnormalities of tissue structure by detecting microscopic changes in water mobility that develop when disease alters the organization of normal tissue, providing tissue characterization at a cellular level. This technique appears particularly appealing for probing diseases that affect the musculoskeletal system [53]. DWI measurements are accomplished by application of diffusion-sensitizing gradients. These gradients cause phase accrual in the spins of the tissue, which is then reversed and reduced to zero if the spins are stationary. However, water undergoing diffusion accrues a random amount of phase and does not refocus, resulting in signal loss in tissue undergoing diffusion. The amount of diffusion weighting applied depends on the amplitude of the diffusion-sensitizing gradients (b values) [54].

Delayed gadolinium-enhanced imaging shows promise in mapping the distribution of glycosaminoglycans in cartilage, which may have important implications for longitudinal evaluations of cartilage [55, 56]. This technique works by allowing negatively charged gadolinium–diethylenetriamine pentaacetic acid (DTPA) to distribute in cartilage in inverse proportion to the negatively charged glycosaminoglycans.

For anatomic imaging of menisci short echo-times (TEs) are necessary, including conventional spin-echo T1-weighted, proton-density, or gradient-echo sequences [57]. Some advocate that fast spin-echo proton density-weighted sequences are adequate for imaging the menisci, however the gain in time is traded-off by a slightly sensitivity drop off (from 90% to 80%) [58]. Although no evidence indicates that the use of fat-suppression increases the accuracy of meniscal tears, this use has gained widespread acceptance. Fat-suppression increases the dynamic range of signal in the menisci, making meniscal tears more conspicuous.

Although MR imaging of the menisci and cruciate ligaments of the knee in adolescents is sensitive, specific, and accurate [59], 3-Tesla MR imaging allows increased signal-to-noise ratio, increased resolution, and faster scanning times. Studies on the diagnostic performance of 3-Tesla MR imaging for assessment of knees in children and adolescents are currently sparse. Nevertheless, studies in adult knees showed high sensitivity and specificity of MR imaging for detection of anterior cruciate ligament (ACL) tears and medial and lateral meniscal tears, with lower sensitivity (below 70%) for the lateral meniscus [60]. Challenges with chemical shift artifacts at the knee should be further investigated in the future.

The use of multiple receiver coil elements and integrated parallel imaging techniques which use fewer echoes than conventional techniques to obtain the desired resolution represent a great advance in the imaging of the knee [61, 62]. These new approaches are especially important for the pediatric population given the potential for reduction in the scanning time.
REFERENCES


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