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MRI of Sports Injuries in Children and Adolescents: What's Different from Adults

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Abstract As the pediatric population continues to increase its participation in organized athletics, there has been a corresponding increase in associated injuries. The lower extremity is the most frequently involved site in individuals age 5–18, representing about 60 % of all injuries. Children and adolescents are susceptible to injuries that differ from adults. The pelvis, knee, and ankle all present unique diagnostic challenges to the physician. MR can be helpful in the young athlete, as it can better demonstrate apophyseal, physeal, or soft tissue injury that might otherwise be unapparent or underestimated.

Keywords Sports injuries · Pediatrics · MRI · Apophysitis · Avulsion fracture · Physeal injury

Introduction

An increasing number of children and adolescents from the age of 5 to 18 are participating in organized athletic activities. In this same patient population, there has been a corresponding increase of sports-related injuries. With an estimated 45 million children participating in organized sports within the USA and an estimated more than one third seeking medical care for an athletic-related injury, it is important for physicians to be aware of injuries that affect pediatric patients [1]. The competitive nature of organized sports has also shifted the emphasis from multi-sport participation over different seasons to year-long single sport participation, which predisposes young athletes to both overuse and acute injuries.

The unique structural physiology of the growing skeleton causes children to sustain different injuries than adults. Physicians, coaches, and parents must therefore be aware of the effects of sporting activity on the musculoskeletal system in young athletes. Rapid bone growth leads to alterations in bone mineral density and inequalities between bone length and muscle length. Repetitive forces and activity in this setting render the young athlete susceptible to both overuse and acute injuries in the form of apophysitis, avulsion fractures, and physeal injuries [2–4]. About 60 % of all sports-related injuries within those age 5–18 involve the lower extremity [5•].

The pediatric population can be subdivided into the school-aged population (age 5–12) and adolescence (age 13–18). Younger children have under-developed fine motor skills relative to their older cohorts. About 50 % of all injuries within the younger age group are traumatic, with nearly three quarters of all injuries being osseous [5•]. This increased propensity for fractures has been attributed to lower bone mineral density [6].

Adolescents suffer from slightly varying injuries relative to their younger counterparts. Adolescents are prone to overuse injuries in a pattern similar to young adults. Adolescents are also susceptible to acute traumatic injury and represent a greater percentage of the pediatric

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population suffering from a sports injury [5•]. Adolescents have greater body mass, leading them to being more prone to injuries in which there may be collisions with another competitor. Increased injury rates are observed in football, rugby, and soccer with increased age of the participants [3]. The rapid growth adolescents experience leaves the apophyseal and physeal cartilage susceptible to injury.

The Hip and Pelvis

Injuries at the pediatric pelvis and hips have particular characteristics that differ from adults. As with other sites of injury in children and adolescents, injuries are commonly due to repetitive stress rather than a single traumatic event. The three most common injuries are labral injuries, apophysitis, and avulsion fractures [5•]. As children age, injuries at the hip and pelvis increasingly are soft tissue injuries, such as contusions and strains. These injuries demonstrate similar MR imaging characteristics to adults, including intramuscular edema or hemorrhage.

For patients participating in athletic activities who present with pelvic pain felt to be of musculoskeletal origin, an AP radiograph of the pelvis is considered to be the best initial imaging study. False profile and Dunn lateral views can also be helpful in characterizing acetabular version and coverage, as well as femoral head-neck offset. These radiographs may be sufficient in identifying avulsion fractures, slipped capital femoral epiphysis, acetabular rim fractures, or femoroacetabular impingement. Radiographs might also be helpful if the clinical presentation is atypical or the patient fails to respond to appropriate therapy in the setting of suspected apophysitis.

The next best imaging assessment for the pediatric athlete is MRI, which may assist in delineating entities such as a labral tear and apophysitis. It is important that physicians consider a labral tear as a source of pain, as labral tears constitute more than one-third of all injuries at the hip [5•]. The imaging features of a labral tear in the pediatric patient are often similar to those in adults. However, labral and cartilage degeneration are unexpected unless there is underlying hip dysplasia. Patients with hip dysplasia demonstrate the effects of long-term overload at the acetabular rim; these patients often have a hypertrophic labrum and may have complex labral tears.

Many labral tears in the pediatric population are seen with femoral acetabular impingement (FAI). Young athletes who play certain sports, including hockey, soccer, and basketball, appear to have an increased risk of having FAI and labral tears [7, 8]. In FAI, radiographs may show acetabular retroversion and femoral neck osseous proliferation. MR will not only reaffirm the presence of an increased alpha angle and decreased femoral neck-head ratio, it will also allow evaluation for early chondromalacia, labral tears, and chondrolabral delamination [9]. Abnormalities are more common at the anterior and anterosuperior labrum and anterosuperior cartilage, which are best assessed with arthrographic sequences (Fig. 1) [10].

Apophysitis and avulsion fractures are injuries unique to adolescents. An apophysis is a site of bone growth that originates separately from its primary bone and fuses upon skeletal maturity. The apophyses in the pelvis become evident around ages 13–15 and fuse in the 20s, although the lesser trochanter is first typically visualized earlier at 9–13 and fuses by 17 [11]. The apophysis has a slow rate of bone turnover and as a result is 2–5 times weaker than the adjacent supporting soft tissues [12•]. Young athletes are prone to apophyseal injury because apophyseal ossification occurs concurrent with puberty when imbalances occur between bone growth and myotendinous tension. Moreover, structural alterations of the normal developing cartilage at the physes and apophyses within adolescents lead to injuries at lower stresses. There is a progression from the interdigitation of cartilage and bone in children to the fused bone in adults. In adolescents, the intermediary phase that results in portions of calcified and non-calcified cartilage creates a potential clean cleavage plane in which apophysitis or an avulsion fracture might readily occur [13].

Apophysitis is an overuse injury that occurs after repetitive stress is placed upon an apophysis without sufficient time to allow for recovery. Avulsion fractures are caused by forceful, eccentric contractions of a tendon upon its bony insertion and are more common with sports such

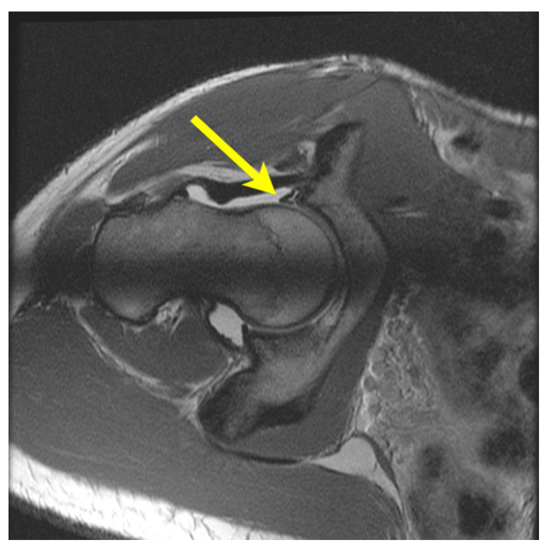

Fig. 1 Diagnosis: labral tear. A 14-year-old male with right hip pain that increases with participation in cross country. There was suspicion of his symptoms being due to a labral tear. A radial proton density hip arthrogram sequence shows extension of fluid into the anterosuperior labrum, consistent with a labral tear (*yellow arrow*) (Color figure online)

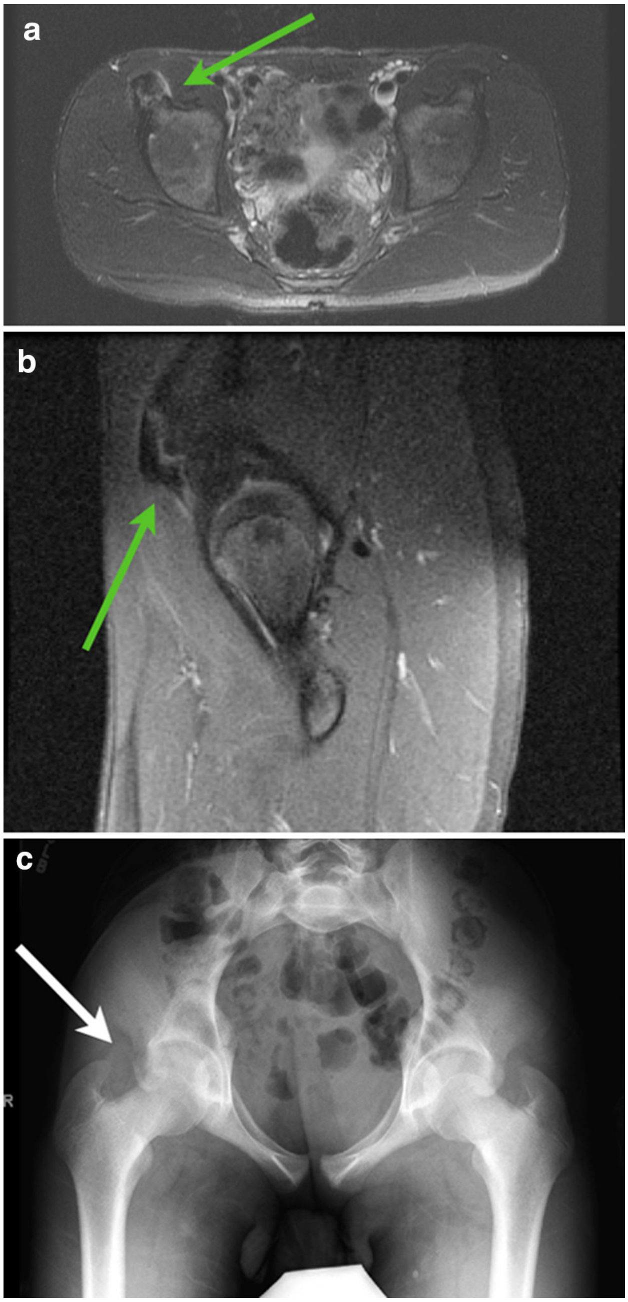

Fig. 2 Diagnosis: avulsion fracture. A 15-year-old male with acute pain at his right anterior inferior iliac spine after a kicking a soccer ball. An axial T2 fat-saturation sequence of the pelvis (**a**) and sagittal proton density fat-saturation sequence of the right hip (**b**) reveal an avulsion fracture of the right anterior inferior iliac spine (*green arrows*), as shown by apophyseal displacement and edema at the physis extending along the ilium. Subsequently, radiographs of the pelvis were obtained, with the avulsion fracture of the anterior inferior iliac spine (*white arrow*) best shown on an inlet view of the pelvis (**c**) (Color figure online)

as soccer and gymnastics (Fig. 2). In adults, similar mechanisms usually cause tendinous strains or tears. In young athletes, because of the weakness at the apophysis, injury at the apophyseal cartilage is much more likely than myotendinous. Any one of the pelvic apophyses may be injured, with the ischial tuberosity, anterior inferior iliac spine, and anterior superior iliac spine representing the majority of injuries; the pubic body, iliac crest, greater trochanter, and lesser trochanter are also susceptible [11].

If radiographs are initially performed, an acute apophyseal fracture may be evident. In apophysitis, radiographs may be normal or may show apophyseal margin irregularity and fragmentation. Other findings of apophysitis can include sclerosis, physeal widening, and focal osteopenia.

On MR, the findings of apophysitis typically include subtle physeal widening and physeal edema, best appreciated on fluid sensitive sequences (Fig. 3). There may be edema within the adjacent host bone and musculature [14]. It should be noted that apophyseal displacement is not typically seen [14]. When there is significant apophyseal displacement, an avulsion fracture should be considered rather than apophysitis. Additional findings indicative of an avulsion fracture on MR include bony edema, soft tissue edema, and hemorrhage.

Differentiation on MR between a healing avulsion fracture and apophysitis may be challenging, and clinical history becomes critical. Both a healing fracture and apophysitis may demonstrate marrow edema, adjacent soft tissue edema, and osseous proliferation. In the more chronic setting, the apophyseal displacement that can be helpful in confirmation of an avulsion fracture may not be evident due to callus.

The Knee

Growing participation in organized sports has led to a corresponding increase in the frequency and complexity of injuries of the knee in the young athletic population. MRI is especially useful in clarifying ligamentous, cartilaginous, and physeal injuries in the pediatric athlete, which can be distinctly different from those experienced by adults.

The most common complaint of the pediatric athlete is anterior knee pain [15]. As with the hip and pelvis, repetitive injury is more frequent than acute injury. Specific painful entities that are unique to the pediatric patient at the knee include tibial tubercle apophysitis, inferior patellar apophysitis, and juvenile osteochondritis dissecans. Radiographs are considered the most appropriate initial imaging modality in young athletes presenting with knee pain [16, 17]. Standard radiographs may demonstrate an acute fracture, suggest apophysitis, or hint at internal derangement. However, MRI can provide so much more valuable information, with as little as 7 % of all positive radiographic findings being helpful in the interpretation of knee MRI [18].

The imaging features of apophysitis at the knee mimic that seen at other locations, such as at the hip. Osgood-

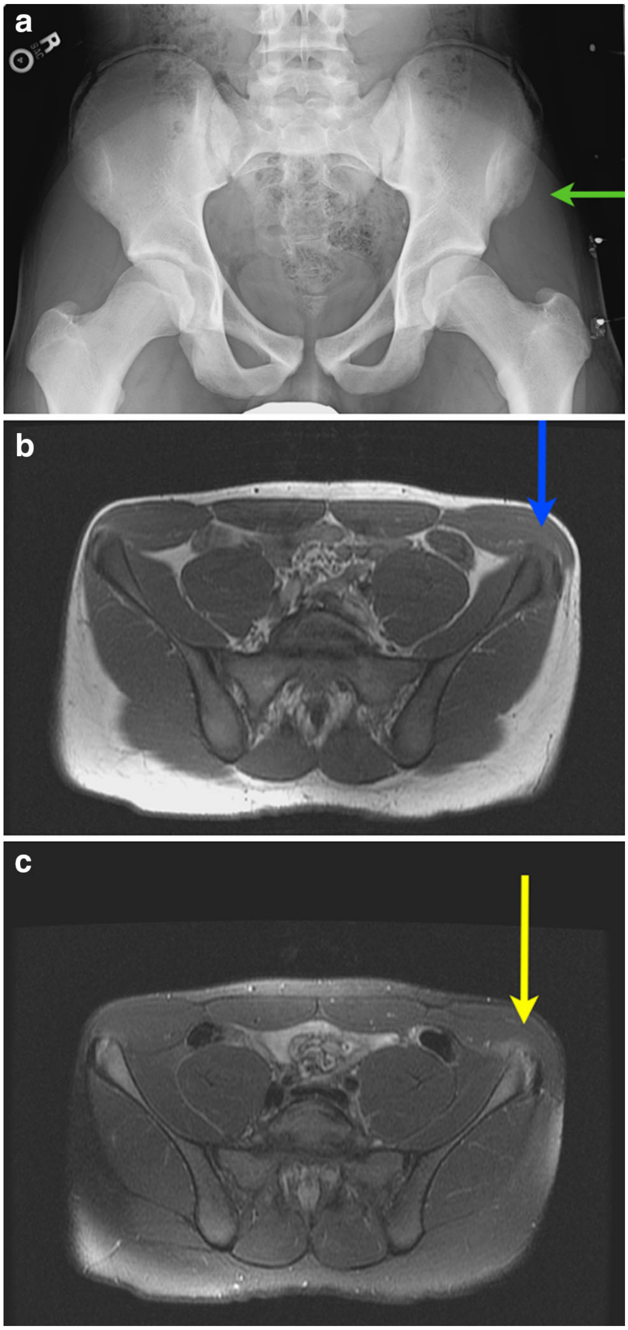

Fig. 3 Diagnosis: apophysitis. A 15-year-old male with pain localized to the left anterior superior iliac spine, exacerbated by his participation in track. He was clinically diagnosed with apophysitis, which was confirmed by the pelvic radiograph and pelvic MRI. **a** An AP view of the pelvis demonstrates osseous irregularity and sclerosis at the left anterior superior iliac spine (*green arrow*), consistent with apophysitis. **b** An axial T1-weighted sequence shows osseous irregularity and physeal widening at the left anterior superior iliac spine (*blue arrow*). **c** An axial T2 fat-saturation sequence demonstrates mild marrow and soft tissue edema at the left anterior superior iliac spine with physeal widening (*yellow arrow*), confirming apophysitis (Color figure online)

Schlatter disease is a traction apophysitis involving the distal attachment of the patellar tendon at the tibial tubercle. It is more commonly seen in males from age 12 to 15 and females from 8 to 12, and may be bilateral in up to 50 % [12•]. The tibial tubercle is an anteroinferior extension of the tibial epiphysis and is particularly susceptible to overuse injury [19]. MR may be helpful in the differentiation between the normal irregularity of the ossification center of the tibial tubercle and Osgood-Schlatter disease. Besides apophyseal irregularity, in Osgood-Schlatter disease 50 % of MR examinations may demonstrate multiple bodies within the distal portion of the patellar tendon that follow marrow signal [20]. There is often increased T2 signal within the patellar tendon and fluid within the infrapatellar bursa (Fig. 4) [20].

Sinding-Larsen-Johannson syndrome is a traction apophysitis involving the inferior pole of the patella, typically affecting individuals age 10–14. The imaging features on MR may include irregularity of the inferior pole of the patella, increased T2 signal within the patellar tendon, and bodies within the proximal patellar tendon following marrow signal (Fig. 5).

The repeated stress of athletic activities can exert excessive tension on the physis. While repetitive injury in the lower extremity occurs less frequently than at other sites in the body, it is of particular concern for the athletic child or adolescent. In the lower extremity, the knee is the most frequently involved site of physeal stress injury and is often associated with a history of running, particularly long distance running. MR may be of particular utility in the assessment of chronic physeal injury, as its multiplanar capabilities and enhanced contrast may assist when radiographs are equivocal, and its lack of ionizing radiation makes it highly suitable to the pediatric patient. MR may demonstrate metaphyseal edema and elongated foci of T2 hyperintense cartilage signal at the site of physeal widening, typically a portion of the distal femoral physis or proximal tibial physis (Fig. 6) [4]. This imaging appearance has been attributed to repetitive stress leading to inhibition of normal bone formation with hypertrophic cartilage at this site. Unlike an acute Salter Harris type 1 fracture, in which there is a fracture through the physis, physeal stress injury may show only focal physeal widening, no epiphyseal displacement, and no definite fracture. With the appropriate treatment of rest for 3–5 weeks, the imaging appearance will return to normal [21]. Physeal stress must also be distinguished from normal physiologic periphyseal edema that may occur with skeletal maturation. As adolescents begin physeal fusion, the initial sites of osseous bridging may be less flexible than other sites of the

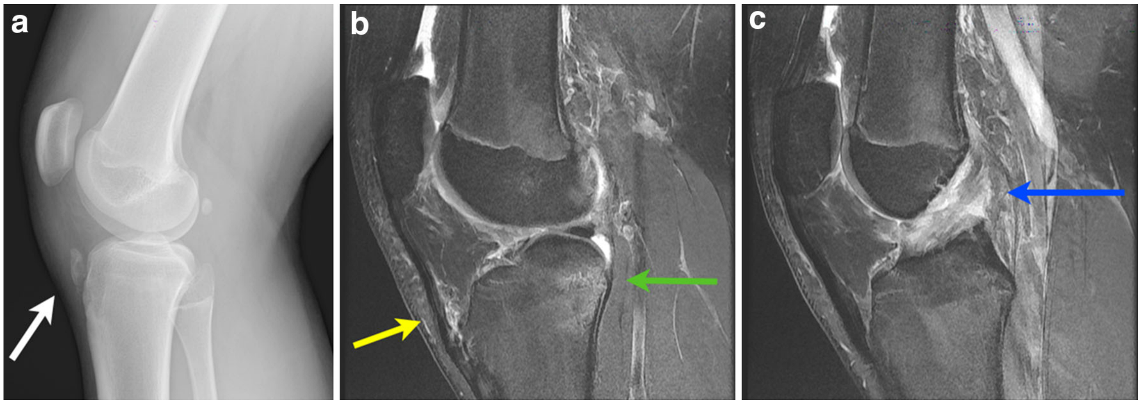

Fig. 4 Diagnosis: Osgood-Schlatter disease. A 14-year-old male football player with chronic anterior knee pain who experienced acute knee pain after jumping and landing awkwardly. A lateral radiograph of the right knee **a** shows osseous fragmentation of the tibial tuberosity and soft tissue swelling (*white arrow*). A sagittal proton density fat-saturation sequence (**b**) shows hyperintense signal, fraying, deep infrapatellar bursitis, tibial tuberosity irregularity, and slight enlargement of the distal patellar tendon (*yellow arrow*), consistent with Osgood-Schlatter disease. Marrow edema (*green arrow*) at the posterolateral tibial plateau on this image represented an osseous contusion related to an acute ACL tear (**c** *blue arrow*) (Color figure online)

Fig. 5 Diagnosis: Sinding-Larssen-Johanssen syndrome. A 10-year-old female with chronic anterior knee pain associated with kickball. A sagittal proton density fat-saturation sequence (**a**) demonstrates hyperintense signal at the proximal patellar tendon and inferior pole of the patella with osseous fragmentation (*white arrow*), consistent with Sinding-Larssen-Johanssen syndrome

physis and more susceptible to microtrauma. This can be differentiated from physeal stress on MR—focal periphyseal edema will demonstrate physeal narrowing with focal edema, while physeal stress will demonstrate physeal widening with elongated foci of cartilage [22].

Patellofemoral pain syndrome is of particular concern in adolescents, as it is the most common cause of chronic knee pain in this age group [5, 20]. This condition more often affects females and typically presents with chronic, dull anterior knee pain at a time of rapid growth. The exact cause of symptoms is uncertain, although it is believed to be associated with patellar maltracking or irritation of nerves from excessive mechanical loading [23]. On MRI, findings may include patella alta, lateral patellar tilt, trochlear dysplasia, or Hoffa’s fat pad edema (Fig. 7). Recent research indicates there may be a role for dynamic (kinematic) MRI of the knee demonstrating greater lateral patellar displacement and patellar tilt in patients [24]. Because patellar maltracking might be caused by muscle imbalance, the vastus medialis muscle may show subtle edema or atrophy [23].

Osteochondritis dissecans most frequently occurs at the knee and may lead to osseous fragmentation and irregularity with cartilage delamination and potential displacement. It most commonly affects patients from age 12 to 19 years. Varying studies have shown a 64–85 % involvement at the posterolateral portion of the medial femoral condyle [25, 26]. It is subdivided into juvenile and adult forms, with the differentiation determined based upon skeletal maturity. It is not entirely understood, although many believe repetitive trauma in the pediatric athlete may lead to vascular injury in the subchondral bone [27]. Moreover, osteochondritis dissecans may be similar to physeal stress. In osteochondritis dissecans, it is theorized that repeated vascular insults might lead to alteration in the normal bone formation at the secondary physis of the epiphysis. This secondary physis of the epiphysis parallels the subchondral bone and, as a site of the most rapid bone formation at the epiphysis, is similar to a metaphyseal equivalent. When subjected to repetitive trauma, apparent elongated foci of hyperintense cartilage will result because

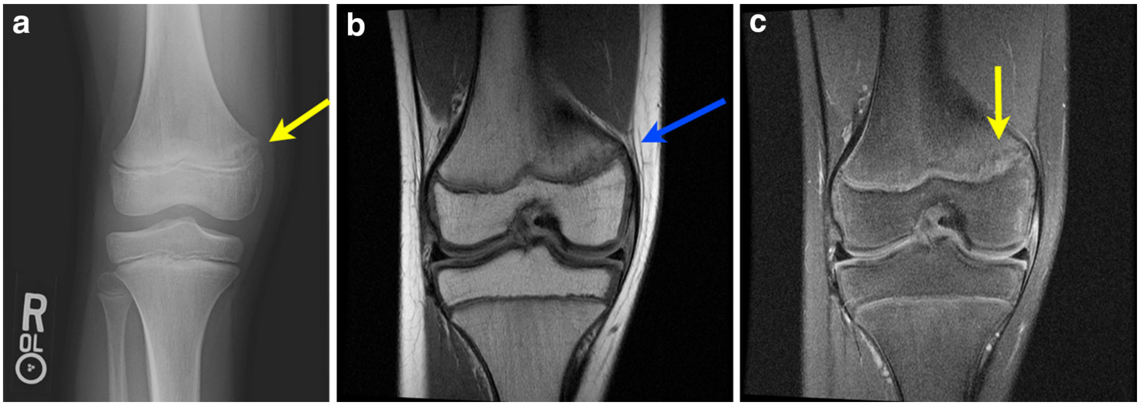

Fig. 6 Diagnosis: physeal stress injury. An 11-year-old male soccer player with chronic medial-sided knee pain. An initial radiograph of the knee was obtained (**a**), showing physeal irregularity and widening at the distal medial femur (*yellow arrow*), indicative of chronic physeal stress injury. Subsequent coronal proton density (**b**) and coronal proton density fat-saturation sequences (**c**) show irregularity of the distal medial femoral physis (*blue arrow* in **b**) with foci of hyperintense elongated physeal signal (*yellow arrow* in **c**) representing hypertrophic cartilage, consistent with physeal stress injury (Color figure online)

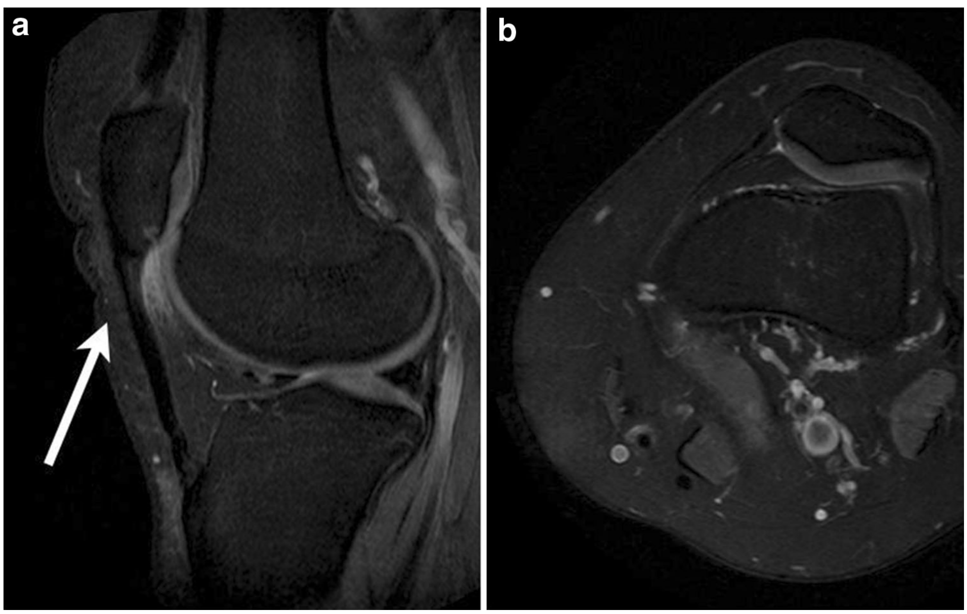

Fig. 7 Diagnosis: patellofemoral pain syndrome. An 18-year-old female with generalized anterior knee pain. A sagittal proton density fat-saturation sequence (**a**) shows edema within the superolateral portion of Hoffa's fat pad (*white arrow*) and patella alta; an axial proton density fat-saturation sequence displays lateral subluxation of the patella (**b**). The history and image findings were consistent with the diagnosis of patellofemoral pain syndrome

of diminished bone proliferation relative to the remainder of the epiphysis, similar in appearance to physeal stress [27]. MR imaging features of osteochondritis dissecans might include cystic signal or extension of fluid signal within the subchondral bone. MR is particularly useful in assessing for instability, as indicated by an osteochondral fragment surrounded by a fluid signal rim or cysts, fluid signal fracture line through the articular cartilage at the osteochondral fragment, or a fluid-filled defect (Fig. 8) [28]. In the juvenile form, there is a 100 % sensitivity and 100 % specificity in the confirmation of instability when all of the following are identified: bright T2 signal surrounds an osteochondral lesion, a second more peripheral rim of low T2 signal surrounds the lesion, and there are multiple defects in the subchondral bone [24]. MR can also be helpful in the differentiation of an osteochondral defect from normal physeal irregularity that may occur in the pediatric population. Normal ossification variability occurs at the posterior femoral condyle with extension beyond the immediate subchondral bone and lacks marrow edema. This can be contrasted by osteochondritis dissecans, which may occur at the intercondylar region, involves the

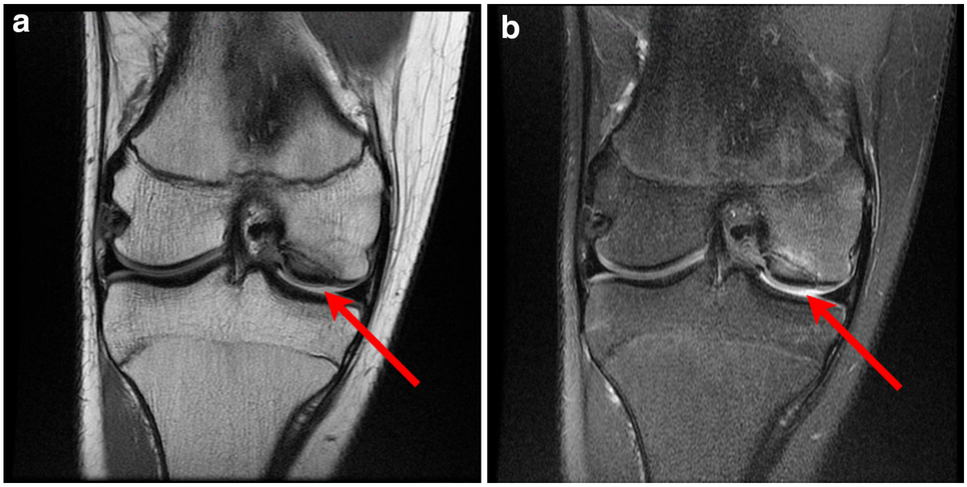

Fig. 8 Diagnosis: osteochondritis dissecans. A 15-year-old male baseball catcher with medial sided knee pain. Coronal proton density (**a**) and coronal proton density fat-saturation (**b**) sequences of the knee demonstrate fluid signal interdigitating between a 9-mm ossific fragment and the remainder of the medial femoral condyle (*red arrow*), consistent with an unstable osteochondral defect (Color figure online)

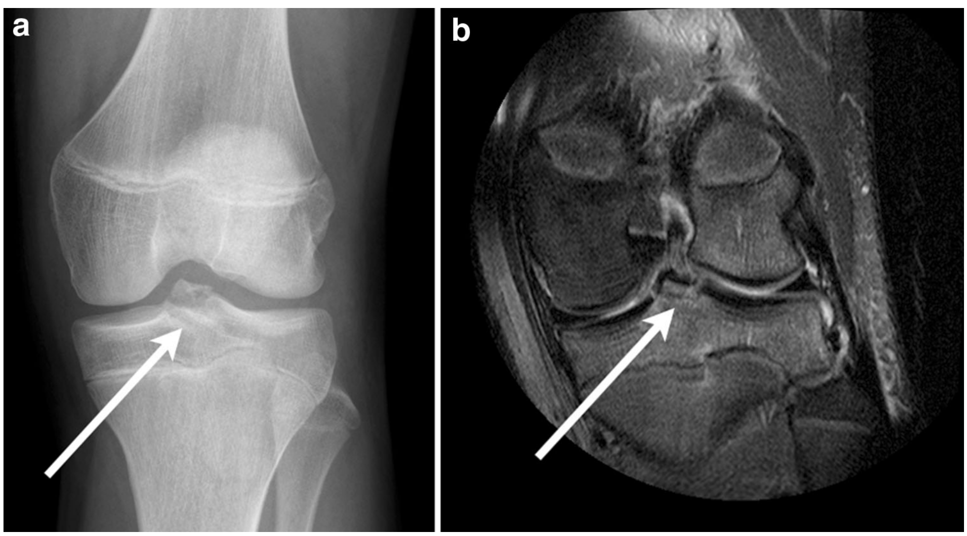

Fig. 9 Diagnosis: tibial spine avulsion fracture. A 14-year-old male football player who suffered immediate left knee pain and swelling after being tackled. An initial AP view of the left knee (**a**) shows an avulsion fracture at the tibial spine (*white arrow*). A coronal proton density fat-saturation sequence of the left knee (**b**) demonstrates the minimally displaced avulsion fracture at the tibial spine at the attachment of the anterior cruciate ligament (*white arrow*)

immediate subchondral bone, and usually demonstrates marrow edema [29].

In the acute setting, fractures, anterior cruciate ligament (ACL) injuries, and meniscal tears constitute the most common knee injuries within pediatric patients. As at the pelvis, avulsion fractures might occur at sites of apophysitis but may also be seen at sites frequently seen in adults. At the knee, the chondrosseous tibial spine is the weakest component of the ACL complex in the skeletally immature patient. For this reason, anterior tibial spine avulsions are relatively common before physeal closure, whereas intrasubstance ACL tears become more prevalent after skeletal maturity (Fig. 9) [30]. In tibial spine avulsion fractures, MR imaging can best assess the integrity of the ACL fibers and whether the fracture fragment is significantly displaced or rotated. MR can also be helpful in demonstrating a concomitant meniscal tear, which most commonly occurs in the anterior horn of the medial meniscus and which may become entrapped under the fracture [31].

Adolescents have similar soft tissue injuries as those seen in young adults. Avulsion fractures at the medial tibial plateau (reverse Segond fracture), lateral tibial plateau (Segond fracture), and fibular styloid (arcuate sign) suggest injuries to the ACL, posterior cruciate ligament, and posterolateral ligaments, respectively [32, 33]. As in young adults, MR may demonstrate similar imaging findings of an acute ACL tear—disruption of the fibers and edema at its site. Associated osseous contusions at the posterior femoral condyle and posterolateral tibial plateau may also be present, indicative of a pivot-shift mechanism (Fig. 10). So-called "kissing contusions" at the lateral femoral condyle and posterolateral tibial plateau are associated with complete ACL tears and represent bony edema caused by contact between the femur and tibia at the time of injury. In young children, these same "kissing contusions" may be present yet the ACL will be intact—this is likely related to the increased ligamentous laxity of young children. Unlike in adolescents, ACL tears are more frequently partial rather than complete [19]. Meniscal injuries are infrequent in young children unless there is an underlying discoid meniscus.

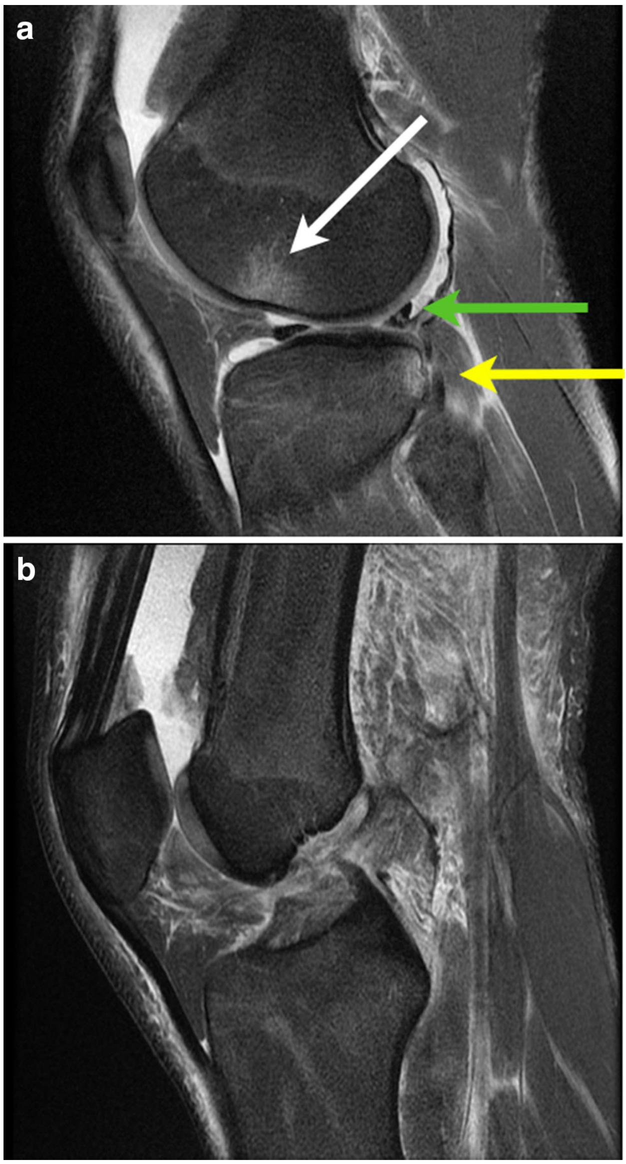

Fig. 10 Diagnosis: anterior cruciate and lateral meniscal tears. A 16-year-old male soccer player with right knee pain and instability after noting that his "cleat got stuck." A sagittal proton density fat-saturation sequence of the right knee (**a**) demonstrates a tear of the lateral meniscus (*green arrow*) in conjunction with contusions of the lateral femoral condyle (*white arrow*) and the posterolateral tibial plateau (*yellow arrow*), suggestive of anterior cruciate ligamentous injury. An additional sagittal proton density fat-saturation sequence (**b**) confirms a complete anterior cruciate ligament tear (Color figure online)

Patellofemoral dislocation is one of the most commonly seen acute injuries at the knee in the pediatric patient. Particular risk factors for recurrent dislocations include an open physis and trochlear dysplasia [34]. The MR imaging appearance of an acute patellofemoral dislocation may be similar to that in adults, including contusions at the medial patella and lateral femoral condyle and tear of the medial patellofemoral ligament with surrounding soft tissue edema (Fig. 11) [35].

Inferior patellar and tibial tuberosity avulsion fractures occur less frequently than avulsion fractures within the pelvis. Similar to the pelvis, clinical history may be most helpful in differentiation between an acute avulsion fracture from apophysitis. Patellar fractures represent up to 6.5 % of all pediatric fractures, with avulsion of the inferior patellar pole constituting up to 73 % of these fractures [36]. Sagittal fluid-sensitive MR sequences can be particularly helpful in assessing for fracture extension into the

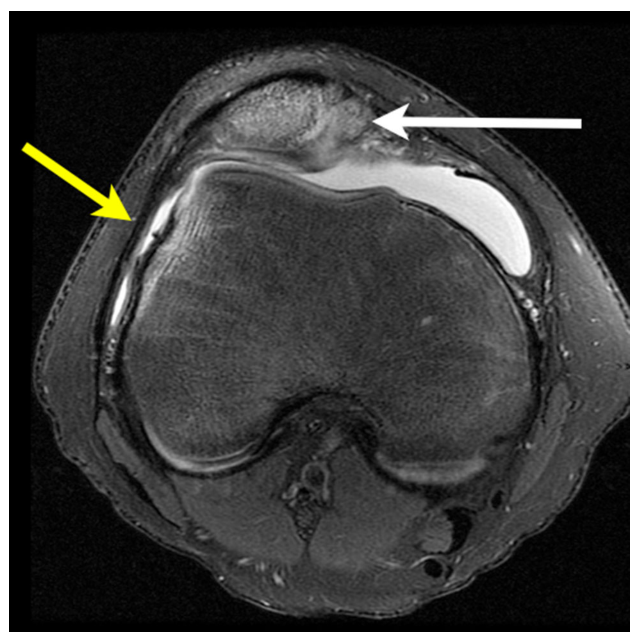

Fig. 11 Diagnosis: patellofemoral dislocation. A 13-year-old male basketball player with recurrent knee instability. An axial proton density saturation sequence of the right knee shows lateral trochlear dysplasia and marrow edema at the medial patella (*white arrow*) and the lateral femoral condyle (*yellow arrow*) representing osseous contusions from transient patellar dislocation (Color figure online)

patellar articular cartilage (Fig. 12) [37]. Tibial tuberosity avulsion fractures are more infrequent. When MR is needed, additional potential sites of marrow edema or soft tissue injury can be confirmed. If there is a question of differentiating a tibial tuberosity avulsion fracture from the apophysitis of Osgood-Schlatter disease, MR might better show fluid signal extension into the physis, which would only occur in an acute fracture [33].

The Ankle

In the pediatric population, injuries at the ankle are less frequent than at the pelvis or knee and are predominantly acute rather than chronic. Ligamentous injuries occur more frequently than osseous, potentially representing 16 % of all injuries in the pediatric athlete, while fractures represent 5 % of all fractures within this age group [38, 39]. Typically, only radiographs are performed in the assessment of acute injury at the ankle in the young athlete. In those who suffer ligamentous injury, the MR imaging features are similar to those in young adults, including demonstration of soft tissue edema and partial or complete ligamentous disruption (Fig. 13). Attention should be paid to the anterior talofibular ligament, calcaneofibular ligament, and distal syndesmotic ligaments, as 90 % of all ligamentous injuries at the ankle are lateral in the pediatric patient population [40].

Osteochondral injuries might also occur at the ankle, although these are fairly infrequent relative to the knee. Osteochondritis dissecans occurs at the medial talar dome or less often at the lateral dome, and similar to that at the knee, MR may be helpful in the determination of instability [41]. Imaging characteristics of osteochondritis dissecans at the ankle parallel that at the knee, including cystic signal or extension of fluid signal within the subchondral bone. A displaced intra-articular body, defect of 5 mm or greater, or fluid signal tracking circumferentially around the intra-articular body is indicative of instability [42].

Acute physeal injury with potential for growth alterations is of concern for the pediatric athlete. There is mild controversy over the utility of MR in the assessment of acute physeal injury [43, 44]. More recent research indicates that MR can be of great use, particularly when no fracture is evident radiographically. MR may detect occult physeal fractures in up to 34 % of all patients who present with symptoms suspicious for an underlying fracture [45]. With MRI in the acute setting, a fracture involving the physis may be best depicted on fluid sensitive sequences with focal physeal widening (or narrowing in a Salter 1 fracture). A high intensity band will traverse the physis and may extend to either the metaphysis and/or epiphysis (Fig. 14). Additional imaging findings may include osseous edema, periosteal elevation, and ligamentous injury [46]. If radiographs show a fracture, MR may also be helpful in the

Fig. 12 Diagnosis: inferior patellar pole fracture. A 13-year-old male with anterior knee pain after falling while running. An MR exam was conducted approximately 1 month later, with a sagittal proton density fat-saturation sequence showing a subacute fracture of the inferior pole of the patella (*yellow arrow*), with the fracture extending to the inferior articular cartilage (Color figure online)

Fig. 13 Diagnosis: distal tibiofibular syndesmotic ligamentous tear. A 14-year-old male with ankle pain and instability for 1 month after an initial football injury. An axial proton density fat-saturation sequence of the right ankle demonstrates disruption of the distal anterior inferior tibiofibular ligament (*white arrow*) with edema at the distal tibiofibular syndesmosis and adjacent soft tissues, consistent with a “high ankle sprain”

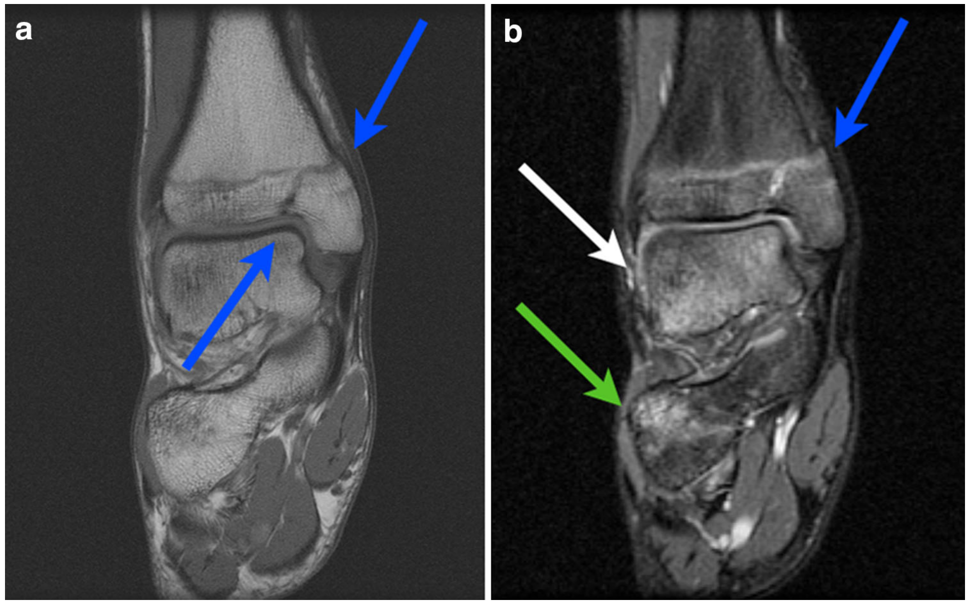

Fig. 14 Diagnosis: acute physeal injury. A 15-year-old male soccer player with ongoing ankle pain for several months. A coronal proton density sequence (**a**) demonstrates a hypointense fracture line within the medial distal tibial epiphysis extending to the physis (*blue arrows*). A coronal proton density fat-saturation sequence (**b**) shows the distal tibial fracture as a hyperintense line with adjacent osseous edema (*blue arrow*). Marrow edema at the talus (*white arrow*) and calcaneus (*green arrow*) represent additional contusions (Color figure online)

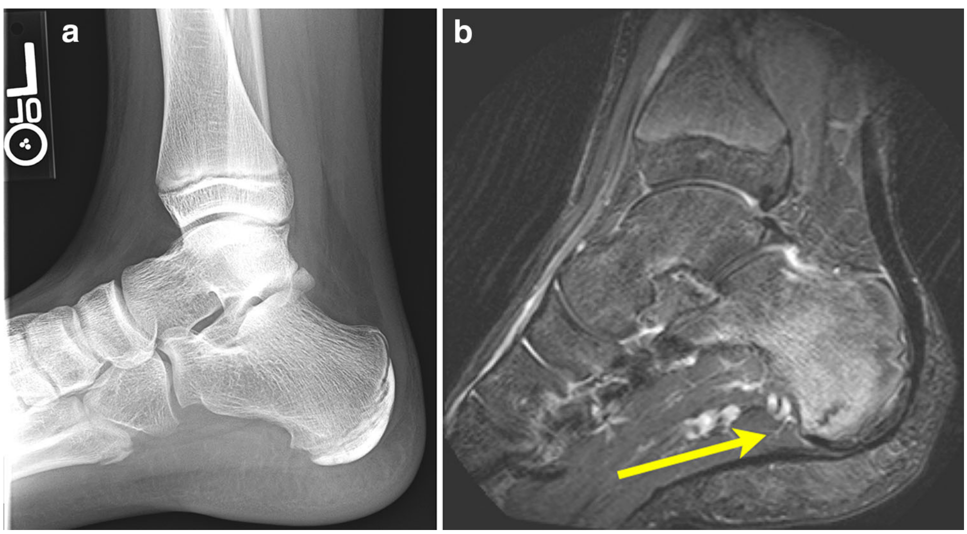

Fig. 15 Diagnosis: calcaneal stress fracture. A 12-year-old male football player with left hindfoot pain associated with running. Initial radiographs (**a**) of the left ankle were within normal limits. Subsequently, an MR of the left ankle was performed. A sagittal inversion recovery sequence (**b**) demonstrates a hypointense fracture line (*yellow arrow*) within the calcaneus with prominent surrounding marrow edema, consistent with a stress fracture (Color figure online)

operative treatment by better depicting the fracture extent and fracture fragment displacement [47].

Later, MR may also be utilized to show physeal alteration from prior physeal fracture. The lower extremity is most frequently involved in aberrant physeal bridging. The distal tibia and distal femur are most commonly involved, and MR is the modality of choice for assessment [48, 49]. At the distal tibia, the anteromedial physis that includes Kump's bump, a convexity of the physis, is most often involved and must be closely scrutinized [44]. The MR imaging features of physeal bridging include continuity of marrow signal between the metaphysis and epiphysis, best shown on T1-weighted sequences. Physeal closure can be confirmed with the absence of continuity of the high cartilaginous signal of the physis on fluid sensitive sequences, with 3D GRE sequences being of particular advantage [49].

Apophysitis may occur at the ankle at the calcaneus. Also termed Sever disease, it is the most frequent cause of heel pain in children. The diagnosis is somewhat controversial, although this repetitive stress injury at the calcaneus appears to be associated with running, with participants in long distance running and soccer more susceptible [50]. As with other apophyseal injuries, it frequently occurs during rapid periods of growth, with males age 10–12 most commonly affected. As radiographs are often of little help, MR may be helpful by demonstrating calcaneal apophyseal edema, which may extend to the physis and calcaneal tuberosity [51].

Stress fractures may occur in the pediatric population, with the tibia and metatarsals the most common sites of injury [52]. As with other overuse injuries, stress fractures are more common among adolescents than in younger children. Certain sports result in increased susceptibility to stress fractures. Endurance sports such as running that have repetitive compressive forces lead to a greater proportion of stress fractures occurring at the metatarsals, while rapid changes of direction in sports such as tennis and basketball have both compressive and torsional forces that lead to potential stress fractures at the tibia [52]. MR is best in the detection of stress fractures thanks to its superior sensitivity and specificity to both CT and radiographs [53]. As nearly 30 % of adolescents with a stress fracture may demonstrate normal radiographic findings, MR can be particularly useful [46]. MR findings confirming a stress fracture include a hypointense fracture line, marrow edema, periosteal thickening, periosteal edema, and soft tissue edema (Fig. 15) [53].

Conclusion

An increasing number of individuals aged 5–18 are engaging in organized athletic activities, with a corresponding increase of acute and chronic injuries. Young children and adolescents suffer different injuries, as diminished bone density and decreased body size results in more acute traumatic events in younger children, whereas periods of rapid bone growth and increasing osseous maturation leads to more repetitive stress injuries in adolescents. MR is especially useful in the pediatric population because of its lack of ionizing radiation and superb assessment of the physis, apophysis, and adjacent soft tissues. MR may better depict acute or chronic physeal injury, confirm acute or repetitive apophyseal injury, indicate an unstable osteochondral defect, demonstrate a labral tear, or reaffirm patellofemoral syndrome.

Compliance with Ethics Guidelines

Conflict of Interest Cyrus Bateni, Jasjeet Bindra, and Brian Haus have no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by the authors.

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