Musculoskeletal Traumatic Injuries in Children

Characteristic Imaging Findings and Mimickers

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KEYWORDS

- Salter-Harris classification • Greenstick fracture • Bone bridge • Bone growth disturbance
- Pediatric musculoskeletal injury

KEY POINTS

- In the skeletally immature, the physis is more fragile and prone to injury than the ligamentous structures.
- Young children demonstrate greater fracture healing capacity due to the higher biologic activity and osteogenic potential of their periosteum compared with adults.
- Premature physeal closure in children is most often posttraumatic.
- Most acute traumatic bone injuries can be diagnosed with conventional radiographs.
- MR imaging is an excellent tool for differentiation of chronic repetitive trauma versus an acute musculoskeletal injury related to sports participation.

INTRODUCTION

Nearly one-third of emergency department visits in children and adolescents in the United States are related to traumatic injuries.[1] There is increased participation of children and adolescents in sports with a concomitant increased risk of traumatic injuries.[2] Diagnostic imaging of musculoskeletal traumatic injuries in children is crucial for the management of acute and long-term complications. This review article discusses currently available imaging modalities and techniques, physiology of normal bone growth, injury patterns, healing, and complications relevant to the imaging evaluation of musculoskeletal traumatic injuries in children with particular emphasis on the long bones. In addition, mimickers of musculoskeletal traumatic injuries in the pediatric population are reviewed.

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IMAGING MODALITIES AND TECHNIQUES

Radiography

Conventional radiography remains the main imaging tool for assessment of traumatic injuries in children and adults. Most acute traumatic bone injuries can be diagnosed with conventional radiographs. Attention to appropriate positioning and technique is essential for accurate diagnosis of subtle fractures and assessment of joint derangement. The routine use of comparison radiographs remains a controversial topic. In the opinion of the authors, obtaining routine comparison radiographs of the contralateral joint in young children is not always necessary and can increase unnecessary ionizing radiation exposure.[3,4] A more reasonable approach is the evaluation of the initial images and deciding if additional comparison images of the contralateral joint are truly necessary. This approach is in line with the principle of as low as reasonably achievable (ALARA) in the judicious use of ionizing radiation in pediatric patients.

Ultrasound

The application of ultrasound evaluation of musculoskeletal injuries in young patients and adolescents for a variety of specific traumatic injuries is currently growing.[5] The assessment of soft tissue injuries using dynamic maneuvers with reproducibility of symptoms, availability of the contralateral extremity for comparison, lack of radiation exposure, and avoidance of general anesthesia are main attractive features of ultrasound.[6] However, as in all imaging modalities with novel applications, more experience and better normative data of the sonographic appearance of the growing skeleton is needed before expanding the indications of ultrasound in pediatric traumatic injuries.

Computed Tomography

Computed tomography (CT) utilization has been under a substantial amount of scrutiny in recent years due to the inherent risk of ionizing radiation in patients, particularly young children.[7] However, CT 3-dimensional reconstructions play an important role in the evaluation of polytraumatized patients and the assessment of complex fractures requiring emergent surgical planning, such as transitional fractures of the distal tibia, complex pelvic fractures, and unstable vertebral spine fractures.[8,9] Up-to-date reference resources are available from the Image Gently Alliance for the appropriateness criteria and radiation dose optimization when imaging children.[10]

MR Imaging

MR imaging is an excellent tool for the assessment of the bone marrow, cartilaginous components of the growing skeleton, and soft tissues.[11,12] MR imaging allows for superior tissue resolution combined with multiplanar evaluation. Several important indications for the use of MR imaging in children include radiographically occult fractures in pediatric patients with persistent pain, assessment of potential internal derangement, and complications of prior trauma, such as premature physeal closure and growth abnormalities of the developing skeleton. In addition, MR imaging is an excellent tool for differentiation of chronic repetitive trauma versus an acute injury related to sports participation. However, availability in the acute traumatic setting, cost-efficiency, and potential sedation or general anesthesia in young children are important considerations for the use of MR imaging in the assessment of musculoskeletal traumatic injuries.

NORMAL BONE GROWTH OF THE PEDIATRIC SKELETON

Longitudinal growth of the long bones is based on endochondral ossification, in which bone formation depends on a sequential transformation from a cartilaginous precursor. The physis or growth plate is a thin disk structure located between epiphyseal cartilage and the metaphysis that provides this cartilaginous precursor. The presence of the growth plate in children allows for a unique subset of fractures not present in adults. In addition, disruption of the rich vascular supply of the metaphysis can derange the normal apoptosis of chondrocytes in the hypertrophic zone of the physis and prevent normal mineralization leading to growth disturbances[13] (**Fig. 1**).

FRACTURE HEALING IN TRAUMATIC INJURIES IN CHILDREN

Fracture healing is a complex sequential process. Acutely, an immediate inflammatory phase occurs with hematoma formation at the end of the fracture fragments. This is followed by a reparative phase in which initial callous is predominantly immature woven bone. Finally, a remodeling phase occurs in which woven bone matures into lamellar bone and the shape of the bone returns to its initial configuration.[14] Periosteal membranous ossification plays a key role in fracture healing because undifferentiated cells in the periosteum differentiate into osteoblasts capable of forming bone

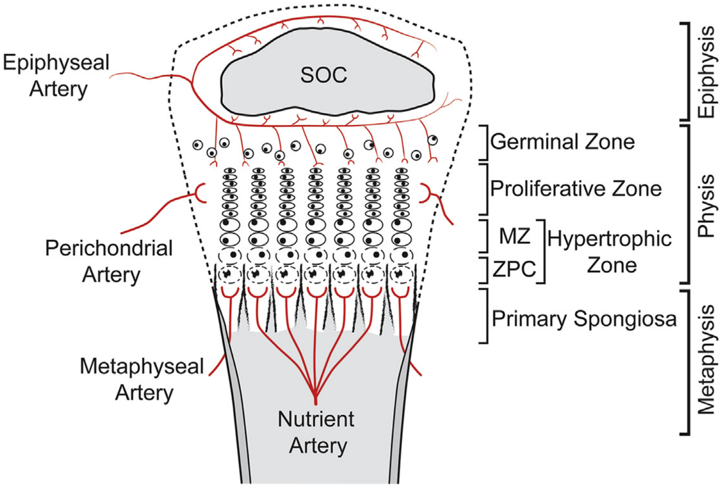

Fig. 1. Normal components of the immature skeleton and endochondral ossification. The epiphyses is the articulating end of a long bone, composed of hyaline cartilage with progressive development of a secondary ossification center (SOC). The physeal cartilage is highly cellular with a distinct columnar arrangement parallel to the long axis of the bones. The chondrocytes originate in the germinal zone near the epiphysis, then advance toward the metaphysis with sequential proliferation, undergo hypertrophy at the maturation zone (MZ), and finally apoptosis with mineralization of the matrix in the zone of provisional calcification (ZPC). The primary spongiosa in the metaphysis is the newest bone formed in the skeleton. There is a rich vascular supply to the metaphysis from nutrient and metaphyseal arteries, rendering this region vulnerable to blood borne diseases and infection. The epiphysis vascular supply through the epiphyseal artery does not form a capillary bed but instead courses through canals in the cartilage, which play a critical role in the formation of the SOC. The perfusion to the epiphysis is fragile and scant, which predisposes the region to avascular necrosis.

without a cartilaginous model. Young children demonstrate greater fracture healing capacity due to the higher biologic activity and osteogenic potential of their periosteum compared with adults (**Fig. 2**). The periosteum in children is also thicker, more vascular, and less frequently disrupted around the entire circumference of the bone, allowing for greater fracture stability.[15,16]

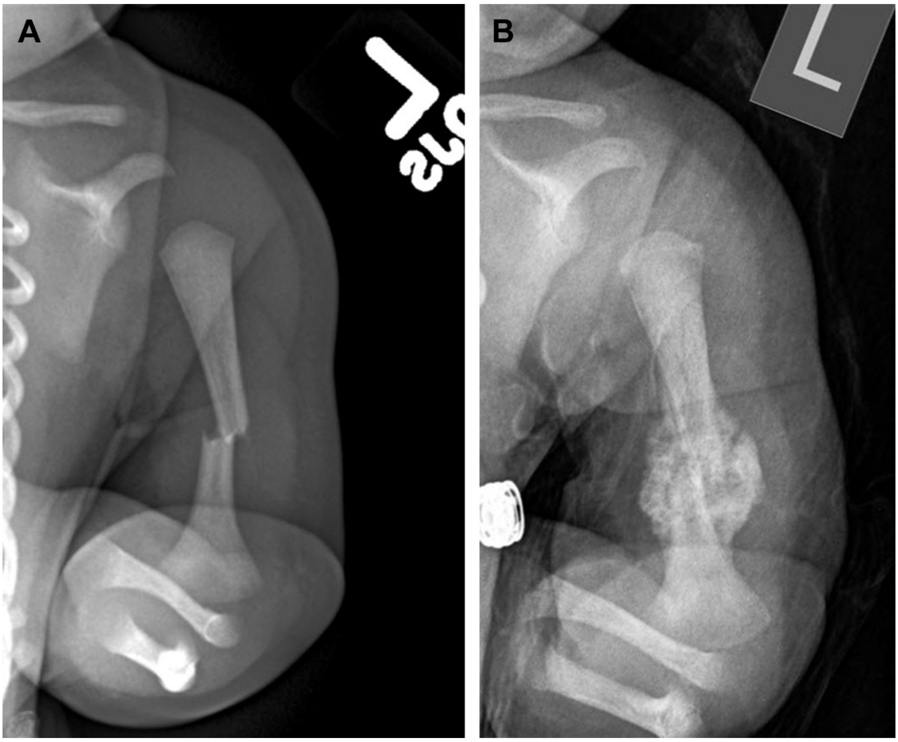

Fig. 2. Newborn infant boy with left arm swelling after difficult breech delivery. (*A*) Initial frontal radiograph of the left humerus demonstrates transverse acute midshaft fracture. (*B*) Follow-up radiograph obtained at 21 days of age demonstrates extensive callous formation and periosteal reaction consistent with interval healing.

CLASSIFICATION OF ACUTE PEDIATRIC FRACTURES

Long Bone Fractures

Pediatric fractures in the long bones can be classified into (1) plastic deformations, (2) greenstick fractures, (3) buckle fractures, (4) physeal fractures, and (5) complete fractures. The first 4 categories are unique to the pediatric skeleton due to anatomic and biomechanical differences from the adult skeleton. The mechanical properties of bone depend on its material composition and its complex architecture.[17] The pediatric bone is less stiff than adult bone and is, therefore, able to absorb more energy before fracturing resulting in a greater capacity to undergo plastic deformation.[18]

Plastic deformation

Plastic deformation is most commonly seen in the forearm, particularly the ulna.[19] The radius and ulna in normal children are often slightly bowed. Longitudinal compressive forces to the ends of long curved tubular bones would cause variable degrees of deformity, depending on the magnitude and duration of the applied force.[20,21] Intermediate forces not exceeding the maximal strength of the bones can result in radiographically occult microfractures and plastic deformation with increased bowing. Radiographs most often demonstrate bowing in 1 bone and fracture in the other (**Fig. 3**A). It is important to recognize that radiographs performed in the first few weeks following acute plastic deformation usually demonstrate absence of or a small amount of new bone formation.[21] If the deformity occurs in children younger than 4 years of age, or if the deformity is less than 20°, the angulation usually corrects with growth.[17]

Greenstick fracture

Greenstick fractures typically occur in long bones, particularly in the radius and ulna. The increased capacity of plastic deformation, lower mineral content, and the increased porosity of bone in children can prolong the time and energy absorption and allow incomplete propagation of the fracture line

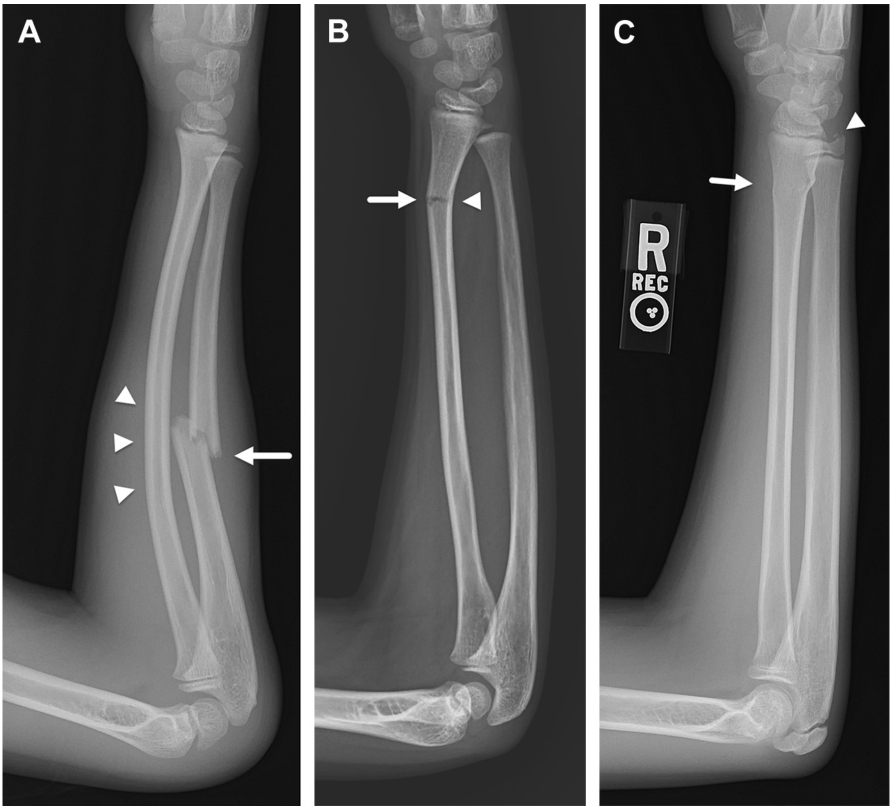

Fig. 3. Long bone fractures in children. (*A*) Lateral radiograph of the forearm shows plastic deformation of the radius (*arrowheads*) and transverse fracture of the ulnar midshaft (*arrow*). (*B*) Lateral radiograph of the forearm shows greenstick fracture of the distal radial shaft with cortical disruption at the radial side (*arrow*) and plastic bowing of the ulnar side (*arrowhead*). (*C*) Lateral radiograph of the forearm shows buckle fracture of the distal radius metadiaphysis (*arrow*) and ulnar styloid avulsion fracture (*arrowhead*).

through the bone.[15,18] This results in plastic deformity in the compression side of the bone with formation of the fracture line along the tension side and a greenstick type fracture (see **Fig. 3**B).

Buckle fracture

Buckle fractures are common. They result from compression failure of the bone at the junction of the metaphysis and diaphysis. Porosity in the metaphysis is larger relative to the denser bone of the diaphysis, causing buckling of the cortex at this location with compressive forces (see **Fig. 3**C). Historically, when a buckle fracture is noted circumferentially along the metaphyseal region, it is called a torus fracture, because of its similarity to the raised band around the base of a classical Greek column.[15] These fractures occur more commonly in the distal radius and ulna, proximal radius, distal tibia and fibula, and small bones of the hand and feet.[22] Buckle fractures can be subtle and a high level of suspicion for these fractures should be present when noting subtle

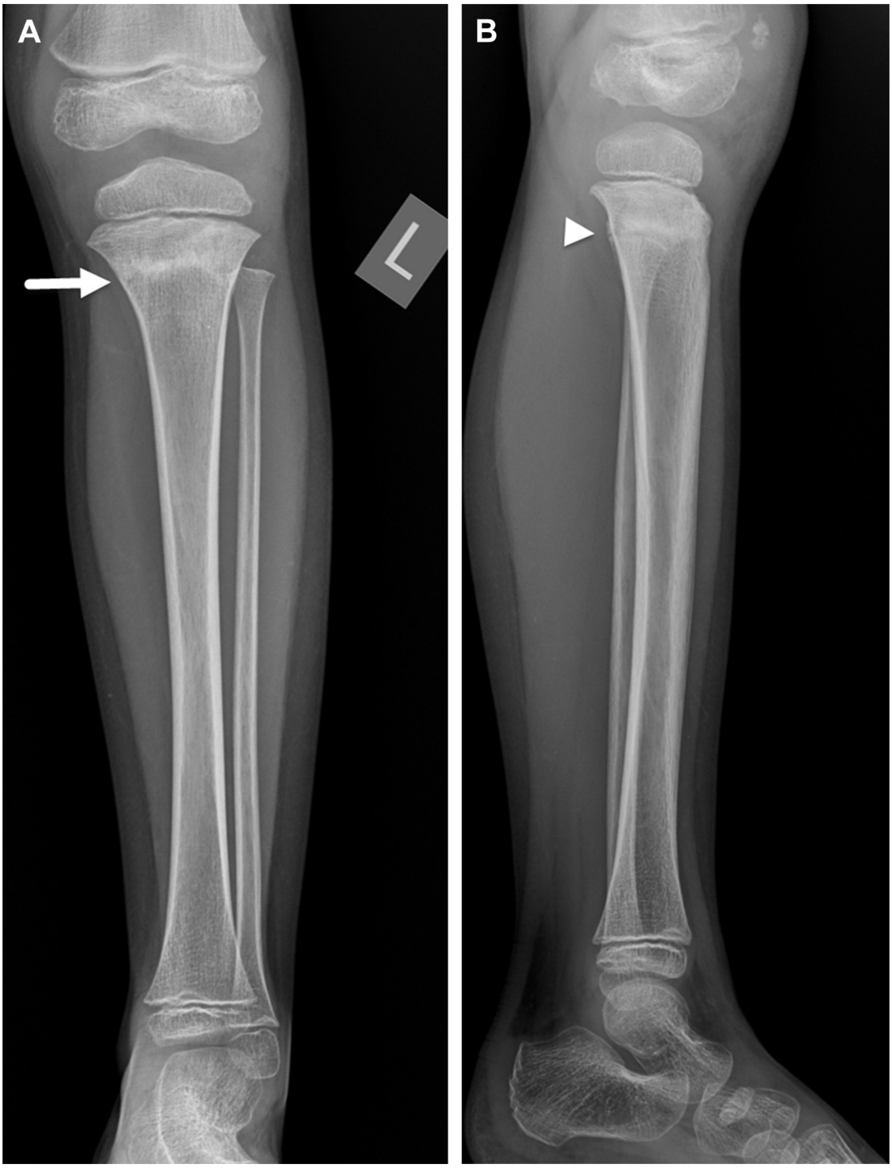

Fig. 4. Buckle fracture of the proximal tibia associated to trampoline injury in a 5-year-old boy. (*A*) Frontal and (*B*) lateral radiographs obtained 4 weeks after initial injury demonstrate subtle buckling of the proximal tibial cortex with dense transverse sclerotic line (*arrow*) and posterior periosteal reaction (*arrowhead*) in keeping with healing changes. The initial radiographs were interpreted as normal (not shown).

increased angulation or small convexity at the junction of the metaphysis and diaphysis in young children. Usually these fractures are stable and can be simply splinted or casted with good result.

In the proximal tibia, a buckle fracture can be seen associated with acute trampoline injuries in young children (aged 2–5 years; **Fig. 4**). The mechanism is likely related to differences in weight when jumping together with a heavier individual and increased impaction forces in the proximal tibia of the young children during landing on the trampoline mat.[23] Other investigators have described similar proximal tibial fractures in the same age population, postulating a hyperextension injury at the knee with forces applied predominantly to the anterior cortex causing compressive forces with anterior cortical buckling, posterior cortical diastases, and possible anterior tilting of the proximal tibial epiphysis.[22,24]

Physeal fractures (Salter-Harris classification)

The physis provides the cartilaginous mold necessary for endochondral ossification and growth of the bone. However, the cartilaginous physis is weaker than its surrounding ossified bone and more susceptible to injury before its closure.[25] The most common location for acute physeal fractures is the distal radius.[26] Usually the physis heals

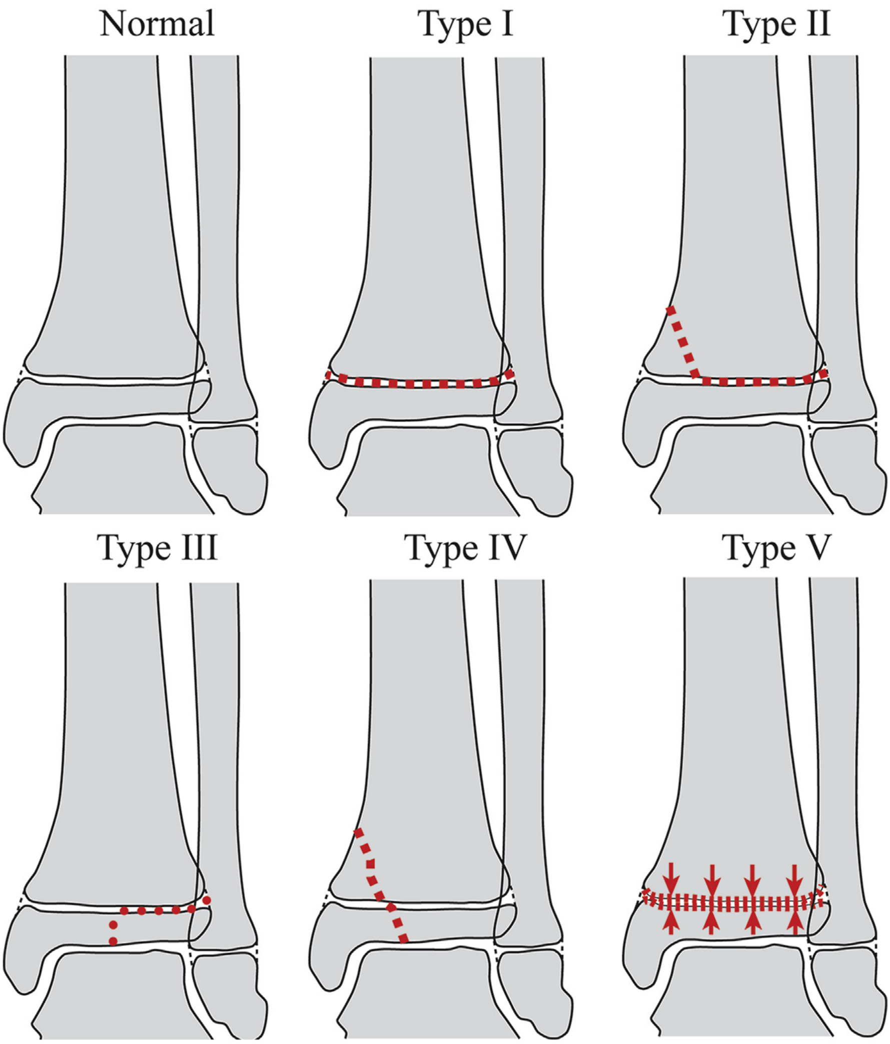

Fig. 5. Salter-Harris Classification in the distal tibia. Type I fracture demonstrates physeal distance from the metaphysis without radiographic evidence of fracture through the ossified bone. Type II fracture is the most common fracture pattern, with the fracture line extending from the physis into the metaphysis. Type III fracture is intra-articular and extends from the epiphyses into the physis. Type IV fracture is also intra-articular and involves both epiphyseal and metaphyseal components with the fracture line passing across the physis. Type V fracture is considered a crush injury of the physis and is very uncommon.

rapidly, between 3 to 6 weeks.[15] This rapid healing provides a limited window for fracture reduction because late reduction (>1 week) potentially leads to physeal damage.[27] Injury to the physis can result in growth abnormalities and premature physeal closure with progressive angular deformity, limb-length discrepancy, and joint incongruity.[13,15,28] Thus, appropriate imaging diagnosis and identification of physeal fractures is critical in limiting potential complications.

The Salter-Harris (SH) classification is the most common system for physeal fracture characterization based on the radiographic appearance of the physeal fracture (**Figs. 5–7**).[29] A more complex classification scheme has been proposed by Ogden,[30] with inclusion of 4 other mechanism of injury patterns in addition to the original 5 in the SH classification. However, it has not been widely used compared with the original SH classification.

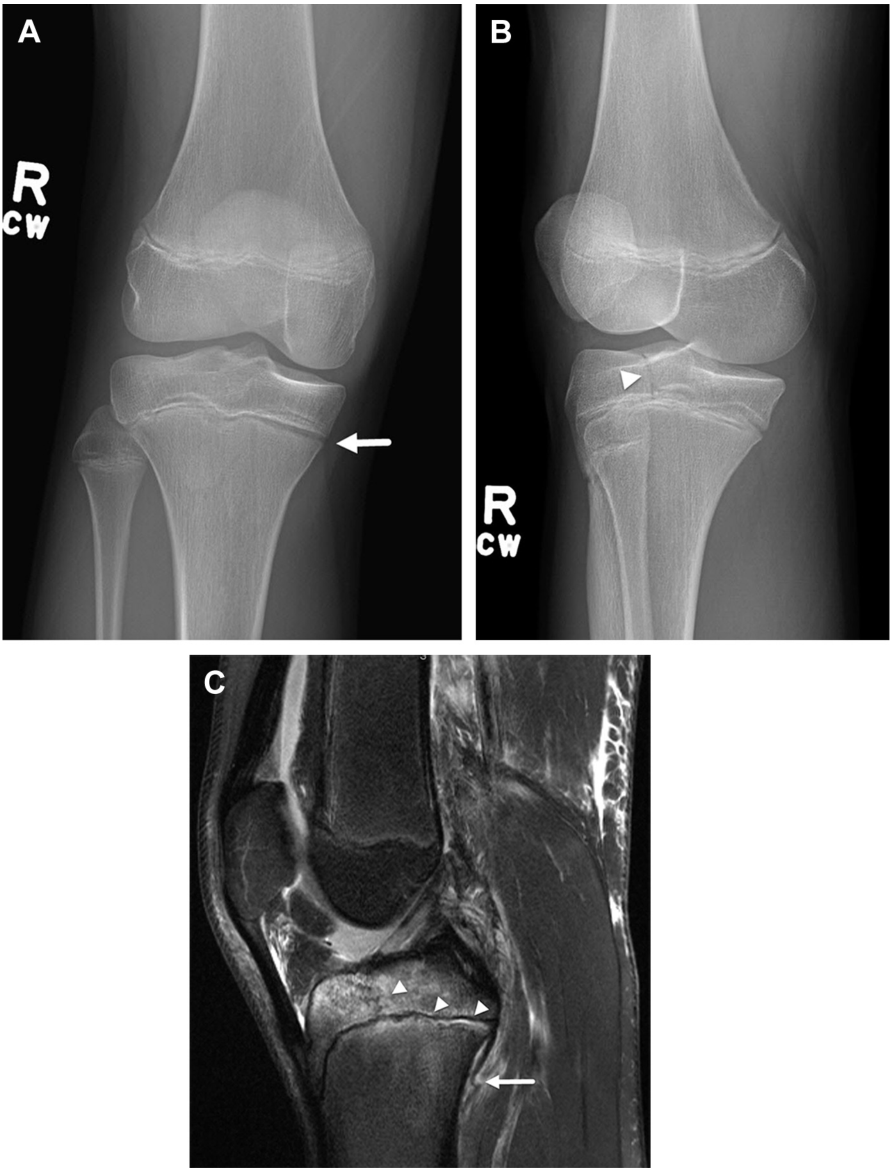

Fig. 6. Salter-Harris type III fracture of the right proximal tibia in a 15-year-old boy after soccer tackle. (*A*) Frontal and (*B*) oblique radiographs demonstrate widening of the medial physis (*arrow*) with epiphyseal lucent fracture line (*arrowhead*). (*C*) Sagittal intermediate-weighted fat-saturated MR image confirming nondisplaced fracture line (*arrowheads*) extending from the posterior physis into the epiphysis. There is disruption and superior retraction of the posterior tibial periosteum (*arrow*).

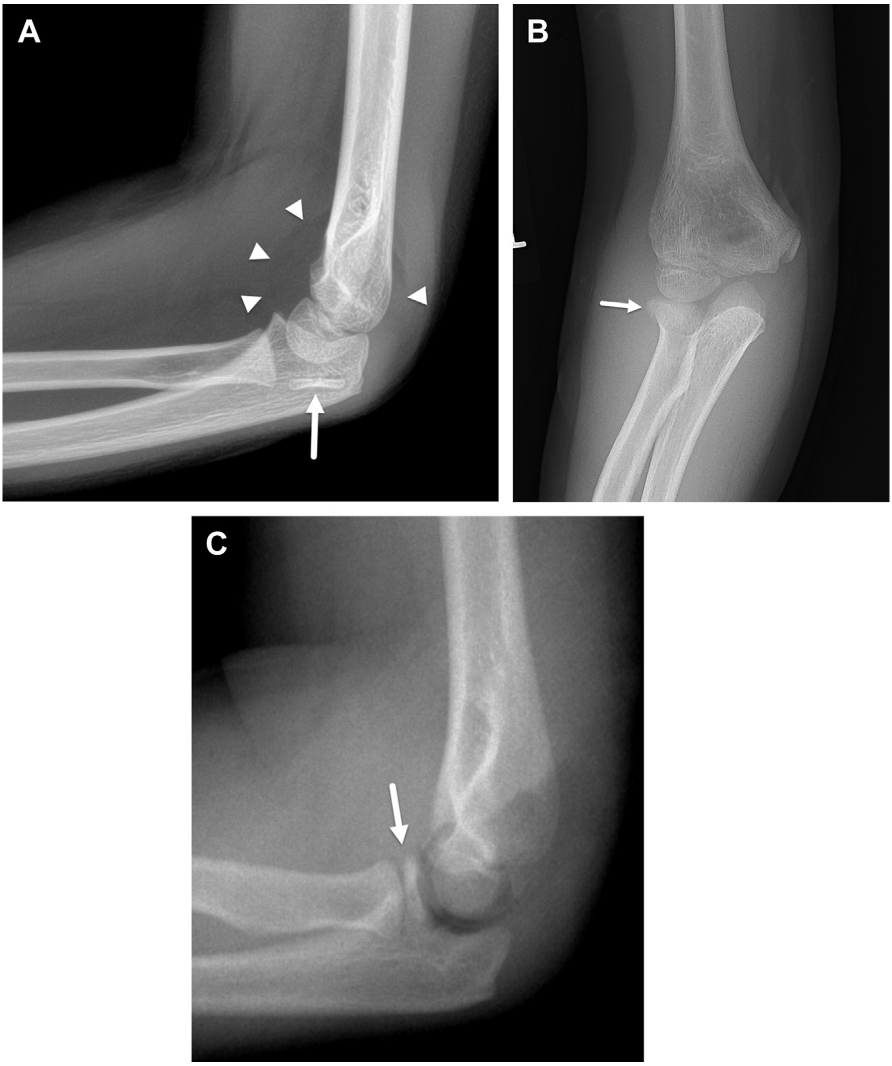

Fig. 7. Salter-Harris type I fracture of the radial head in a 10-year-old boy with blunt trauma to the right elbow after fall. (*A*) Frontal and (*B*) lateral views of the right elbow demonstrate complete physeal separation of the radial head and posterior displacement of the secondary ossification center into the joint (*arrow*) with a joint effusion (*arrowheads*). (*C*) Lateral fluoroscopic image after anatomic reduction of the fracture (*arrow*).

Transitional fractures are a particular subset of distal tibia physeal fractures that occur during the period of distal physeal closure.[31] The 2 fractures included in this specific group of fractures are the triplane fracture (SH IV fracture) and the juvenile Tillaux fracture (SH III fracture). The mechanism of injury is typically supination, external rotation, and compression stress with unpredictable multiplanar fracture patterns.[31,32] The cause of these fractures is related to the orderly asymmetric physeal closure of the distal tibia. The closure of the distal tibia begins centrally, continues medially, and terminates anterolaterally. Radiographically, the central tibial site overlying the medial edge of the talar dome where fusion begins is known as Kumps bump.[33] The type of transitional fracture is determined by the degree of physeal closure and relative weakness of the open physis. Older pediatric patients with more advanced physeal closure present with juvenile Tillaux fractures (**Fig. 8**). Juvenile Tillaux fractures are often intra-articular; thus anatomic reduction of the joint surfaces is recommended to minimize future posttraumatic arthritis. Following radiographic diagnosis, CT is indicated to determine the number of fragments, their configuration, and any displacement of the articular surface. Pediatric patients with a residual displacement of less than 2.5 mm after treatment have a uniformly good result.[32] Because these fractures present almost

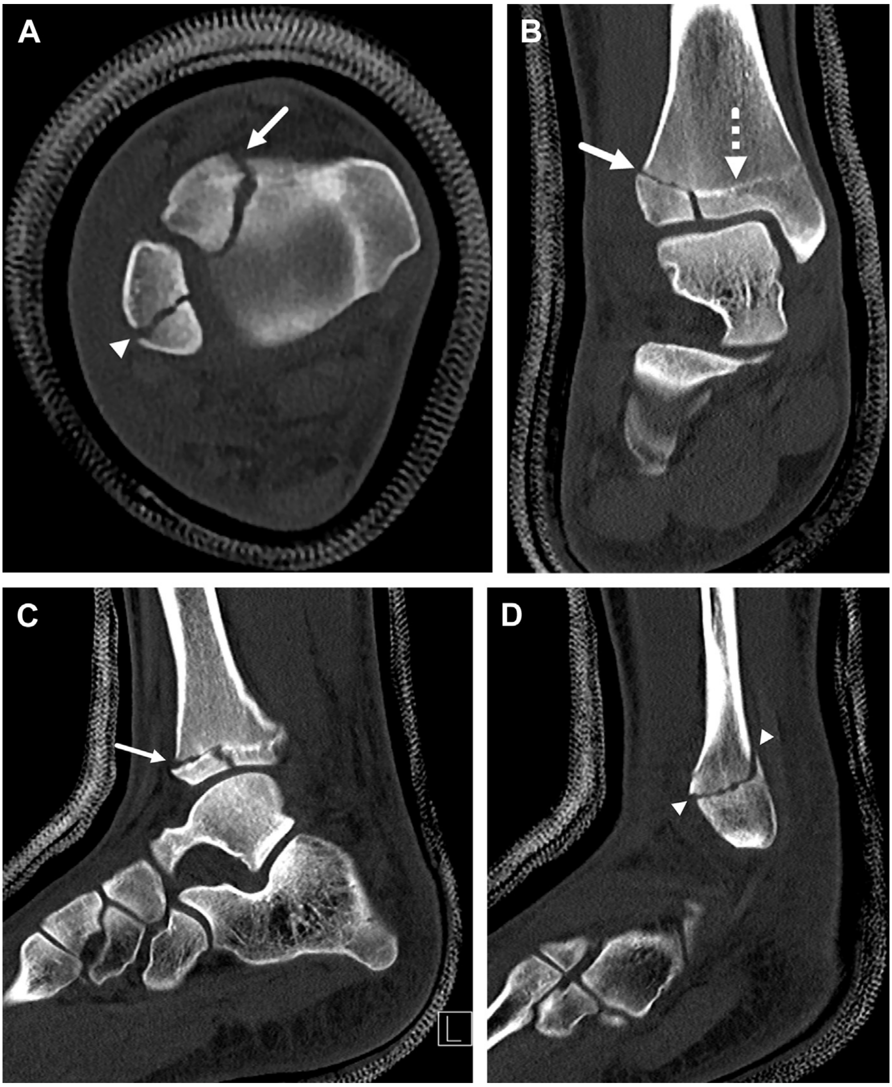

Fig. 8. Salter-Harris type III fracture of the distal tibia (Tillaux fracture) and SH type II fracture of the distal fibula in a 16-year-old female gymnast. (*A*) Axial, (*B*) coronal, and (*C*) sagittal CT images of the tibia demonstrate a SH type III fracture across the anterolateral region of the distal tibial physis with a vertical epiphyseal component (*arrows*). The medial physis demonstrate physiologic closure (*interrupted arrow*). There is approximately 3 mm of displacement of the distal tibial articular surface. (*D*) Sagittal CT image of the distal fibula demonstrates a SH type II fracture across the distal tibial physis and posterior metaphysis (*arrowheads*). The patient underwent open reduction and interval fixation of the tibial fracture.

at the end of physiologic growth, they rarely result in a growth arrest.

Complete Fractures

Fractures propagating through the entire bone can occur in children similar to adults. They are mainly described according to their orientation.

Spiral fractures

Spiral fractures are usually low-velocity injuries associated with a rotational force to the bone. The prototypical spiral fracture is the so-called toddler's fracture of the tibia. This fracture is usually a minimally displaced short spiral oblique fracture of the distal tibial shaft in children younger than 3 years of age (**Fig. 9**).[34] The onset of limping after a minor event or without obvious injury in a young ambulating child, warrants radiographic evaluation to exclude this injury.[35] Clinically, an ankle injury is often suspected with performance of ankle radiographs with the fracture line often evident on the oblique view of the ankle.[36,37] An

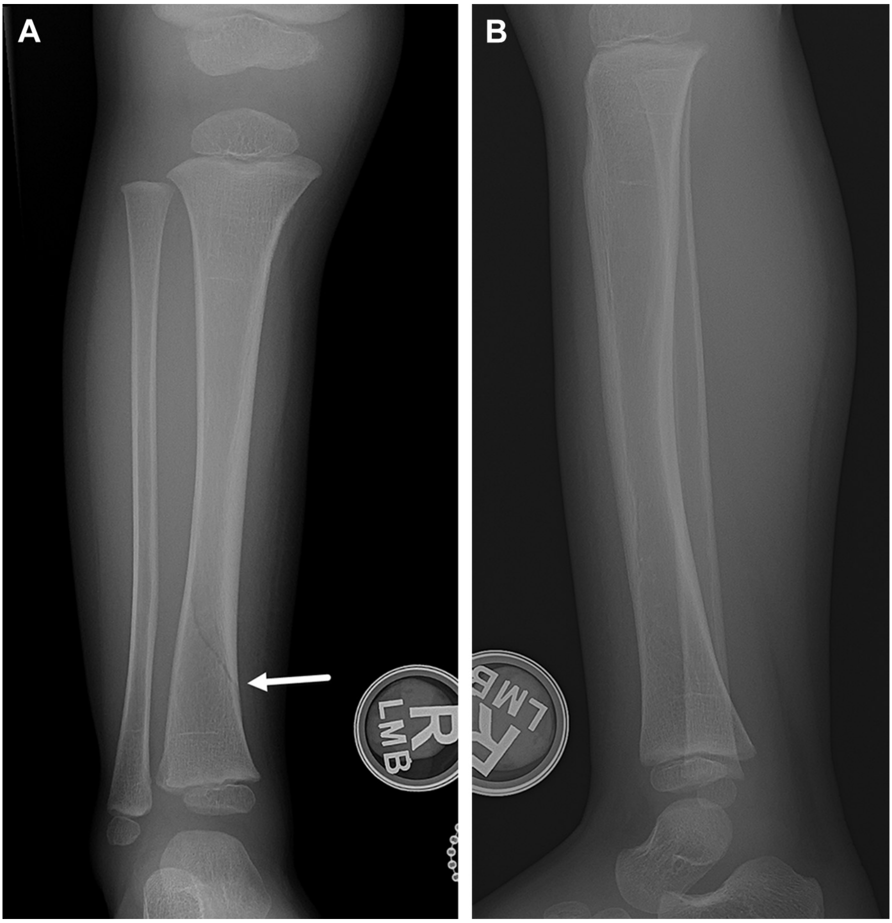

Fig. 9. Toddler fracture in a 2-year-old girl after fall. (*A*) Frontal view of the tibia demonstrates thin lucent spiral fracture line (*arrow*). (*B*) Lateral view of the tibia does not show the nondisplaced tibial fracture, which is not an usual finding in this type of fracture.

intact periosteum usually enables reduction of the fracture by reversing the rotational injury.[15] Some investigators advocate long-leg casting on young children with a history of an acute injury, inability to walk or limp, no constitutional signs, and negative radiographs with clinical concern for a toddler's fracture.[38]

Oblique fractures

Oblique fractures occur diagonally, usually at 30° to the axis, across the diaphysis of a bone. Analogous to complete fractures in the adult, these injuries usually cause more significant disruption of the soft tissues, including the periosteum.[39] These fractures are unstable and fracture reduction is attempted by immobilizing the extremity while applying traction.[15]

Transverse fractures

Transverse fractures through bone in children usually occur from 3-point bending. The periosteum on the side opposite to the force is typically torn. Reduction is usually readily achieved by using the periosteum on the concave side of the fracture force.[39]

Apophyseal Injuries

Apophyses are secondary ossification centers that serve as insertion sites for tendons in the pediatric skeleton. The apophyses have an associated physis that models the shape of bones but does not contribute to their overall length.[11] The distraction associated with musculotendinous activity and the fragility of the physis make apophyses vulnerable to injury.[40] Trauma or unbalanced muscle contractions can cause avulsion of the apophyses with potential ligamentous injuries. Common sites for avulsion injuries include the medial epicondyle of the humerus and the ulnar styloid process of the ulna in the upper extremity, the apophyses around the pelvis, the inferior pole of the patella and tibial tuberosity in the knee, and the medial and lateral malleoli in the ankle (**Fig. 10**).[41]

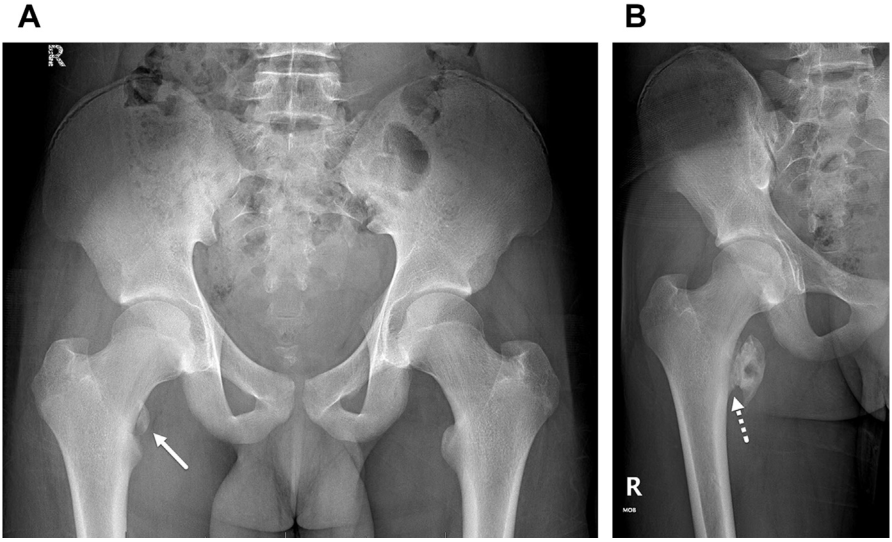

Fig. 10. Lesser trochanteric fracture in a 15-year-old girl after a fall in school gym class. (*A*) Frontal view of the pelvis and both hips during initial evaluation demonstrate superior displacement of the right lesser trochanter apophysis (*arrow*) at the distal insertion site of the iliopsoas muscle. (*B*) Frontal view of the right hip 3 months after the initial injury demonstrates solid bridging callous formation (*interrupted arrow*) in keeping with healing.

CHONDRO-OSSEOUS AND LIGAMENTOUS INJURIES IN CHILDREN

In the skeletally immature, the physis is more fragile than the ligamentous structures. Damage to the ligaments is more common with increasing age and skeletal maturity.[42] The anterior cruciate ligament (ACL) is the most common injured ligament in the knee. Avulsion of the tibial spine occurs in skeletally immature pediatric patients with similar mechanisms as those causing ACL injuries in adults (**Fig. 11**).[2] Tibial spine avulsions can be subtle in conventional radiographs or demonstrate only a joint effusion. Oblique and tunnel views are helpful for assessment of these fractures.[12,41] MR imaging allows for determination of the degree of displacement of the fracture fragment and commonly associated injuries to the collateral ligaments and menisci; crucial information for further management of these fractures.[43,44] Tibial spine avulsion fractures and ACL tears can rarely coexist.[42] However, in the experience of the

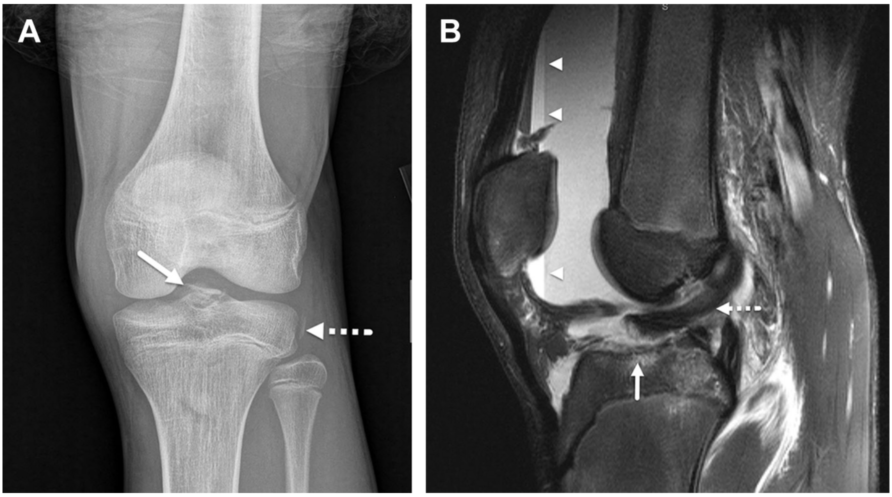

Fig. 11. Tibial spine avulsion fracture in a 14-year-old boy after a fall playing basketball. (*A*) Frontal radiograph of the knee demonstrates avulsion fracture (*arrow*) of the tibial spine (*interrupted arrow*) and Segond fracture of the lateral tibia. (*B*) Sagittal intermediate-weighted MR image confirms complete avulsion fracture (*arrow*) of the tibial spine with an intact ACL (*interrupted arrow*). Large hemarthrosis is also noted (*arrowheads*).

authors, differentiating abnormal signal intensity on MR imaging examinations secondary to ligamentous retraction of an intact ACL from a true ACL tear can be difficult and must be confirmed at the time of arthroscopic evaluation.[45]

CHRONIC SEQUELA OF MUSCULOSKELETAL TRAUMATIC INJURIES IN CHILDREN

Chronic Repetitive Injuries

Chronic repetitive injuries are caused by overuse during prolonged sports-related activities in the immature skeleton of children and adolescents.

Injuries to the physeal region from overuse can be confused with normal developmental changes in the skeletally immature.[11] The specific pattern and location of the injuries are related to the mechanical demands of individual sports. For example, chronic stress injury to the proximal humeral physis in pitchers is caused by rotational forces during overhead throwing and chronic stress injury to the distal radius in gymnasts is secondary to compressive loading during gymnastic routines.[46,47] Radiographic changes may include asymmetric widening and irregularity along the physis, and variable degrees of sclerosis and

Fig. 12. Stress fracture of the proximal tibia in a 15-year-old female runner with recent increased in training regime. Patient presented with posterior knee pain. (*A*) Lateral radiograph of the knee at initial evaluation was normal. (*B*) Axial and (*C*) sagittal fat-saturated T2-weighted MR images obtained after 1 month of persistent knee pain, demonstrate bony edema within the posterior proximal tibia and pericortical soft tissue edema in a similar distribution (*arrowheads*). (*D*) Lateral radiograph of the knee obtained 2 months after (*A*) demonstrates subtle periosteal reaction with very faint cortical lucent fracture (*arrow*) in keeping with tibial stress fracture.

cystic changes in the metaphysis.[47] Similar physeal changes can be seen in the knees of young children with active participation in sports beyond the recreational level. The identification of these changes on MR imaging are important to allow for healing of the physis after cessation of the inciting activity and avoidance of potential complications such as premature physeal closure.[48]

Stress fractures are the result of long-standing workload in healthy bones. Persistent mechanical stresses cause imbalances between cortical resorption and subsequent bone deposition. Osteoblastic activity lags behind causing a failure to repair the bone and development of a stress fracture. Radiographs can be insensitive for the diagnosis of stress fractures and MR imaging is considered the best imaging modality for the presence of these injuries (**Fig. 12**).[49] Typical locations for stress fractures in young athletes include the tibia, fibula, metatarsals, and femur.[50]

Premature Physeal Closure and Growth Abnormalities

Premature physeal closure in children is most often posttraumatic.[13,51] The morbidity associated with premature physeal closure and bony bridge formation is determined by the age of the patient, bone affected, and location of the bony bridge. Younger patients with greater growth potential are at higher risk of more severe complications. For example, bony bridges on the periphery of the physis can lead to angular deformities, and bony bridges in the central portion of the physis can lead to growth arrest and limb length discrepancy (**Fig. 13**).[52] A high level of suspicion for the

Fig. 13. Premature physeal closure of the distal tibia with angular deformity and leg length discrepancy. (*A*) Frontal and (*B*) sagittal CT images demonstrate complex comminuted Salter-Harris type IV fracture (*arrow*) of the distal tibia and small SH type II fracture (*arrowhead*) of the distal fibula at 3 years of age. (*C*) Lateral radiograph of the ankle obtained 6 months after injury shows partial premature closure of the physis (*interrupted arrow*) with varus deformity of the ankle joint related to continued growth of the open distal fibular physis (*arrowhead*). (*D*) Sagittal CT image demonstrates the bony bridge (*interrupted arrow*). The patient underwent distal fibular epiphysiodesis for correction of the angular deformity. (*E*) Orthoroentgenogram obtained 7 years after initial injury shows improvement of the left ankle varus deformity. However, there is a 3 cm leg length discrepancy (right > left) and associated right cephalad pelvic tilt; secondary to the left distal tibia premature physeal closure.

presence of premature physeal closure should be present in the follow-up of pediatric patients with known physeal fractures, particularly in the distal femur, and proximal and distal tibia. These areas have the greatest propensity for complication due to the irregular contour of the physes and greatest growth potential.[53] Conventional radiographs show bony bridges 6 to 12 months after injury. MR imaging using 3-dimensional spoiled gradient recalled echo sequences with fat

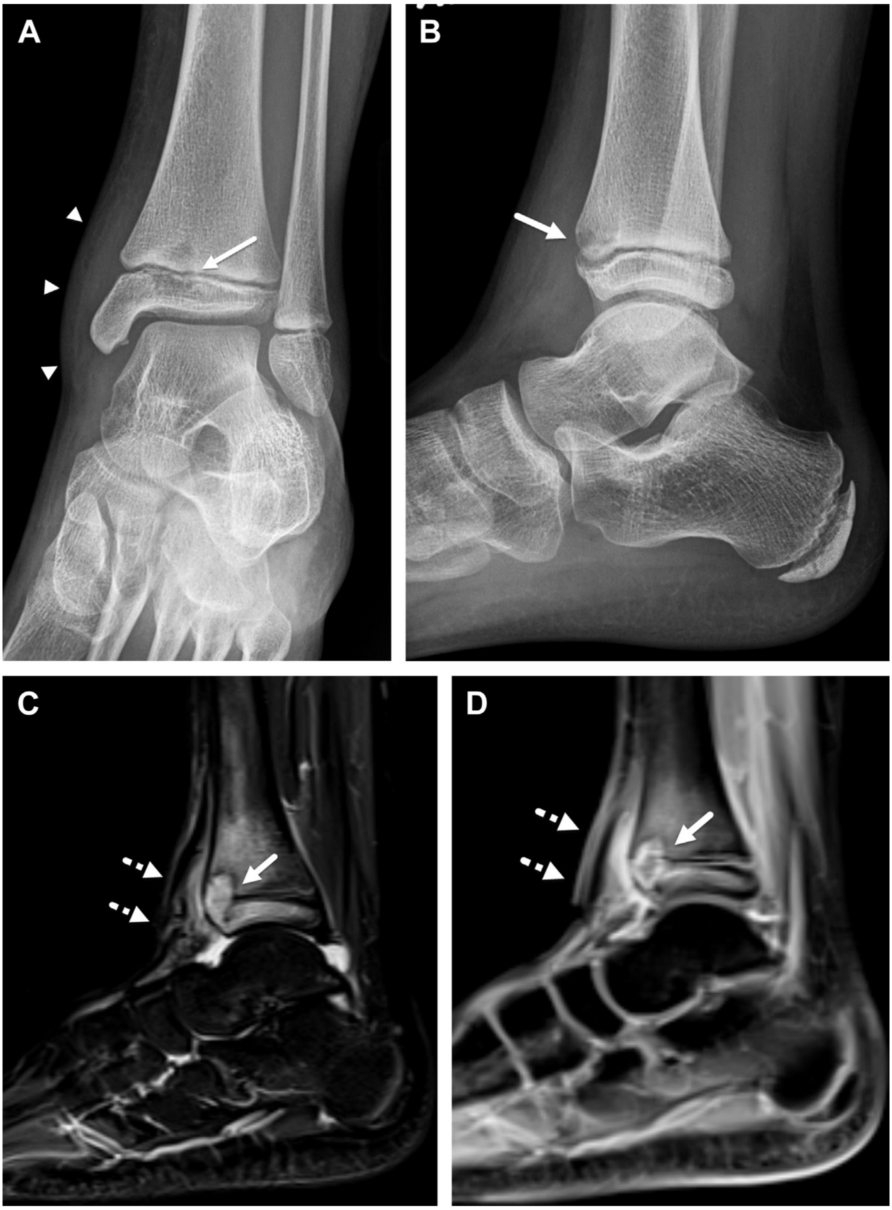

Fig. 14. An 8-year-old girl with left ankle pain and prior history of trauma 2 weeks earlier. (*A*) Frontal and (*B*) lateral radiographs of the ankle demonstrate ill-defined lucency (*arrow*) across the anterior distal tibial metaphysis and epiphysis with adjacent soft tissue swelling (*arrowheads*) concerning for osteomyelitis rather than a fracture. (*C*) Sagittal MR short-tau inversion recovery (STIR) sequence MR image demonstrates well-demarcated focal area of abnormal high signal intensity (*arrow*) corresponding to radiographic abnormality and adjacent soft tissue fluid collection (*interrupted arrows*). (*D*) Postcontrast T1 fat-saturated MR image shows a rim enhancing lesion (*arrow*) confirming osteomyelitis with anterior tibial cortical destruction and soft tissue abscess (*interrupted arrows*). Aspiration and drainage of the tibial abscess showed purulent material and growth of *Aggregatibacter aphrophilus*.

suppression demonstrates physeal discontinuity earlier and provides prognostic information regarding size and location of the bridge.[51,54,55] The general clinical recommendation for resection of a bony bridge and insertion of interposition material is the presence of less than 50% of physeal involvement in a child with 2 years or 2 cm of growth remaining.[56,57]

MIMICKERS OF MUSCULOSKELETAL TRAUMATIC INJURY IN CHILDREN

Musculoskeletal Infection

Musculoskeletal infection sometimes presents as a diagnostic challenge because it can be difficult to recognize in the early stages and can be confused with trauma or even a tumor.[58] A history of minor trauma is reported in up to one-third of children with osteomyelitis.[59] A metaphyseal hematoma due to trauma seems to predispose to bacterial colonization. Conventional radiographs are insensitive for the evaluation of osteomyelitis but are helpful to exclude traumatic injuries or tumors. MR imaging remains the primary modality for evaluation of bone infections and potential drainable abscess (**Fig. 14**).[60]

Symptomatic Anatomic Variants

There are several musculoskeletal congenital and developmental variants that can be associated with pain. Two of the most common entities associated with pain are discoid lateral meniscus in the knee joint and tarsal coalitions in the foot.

Discoid lateral meniscus can present in young patients with knee locking and lateral joint pain. Discoid lateral menisci are prone to tearing.[42,61] MR imaging criteria for the diagnosis of discoid lateral meniscus includes extension of the meniscus into the medial aspect of the joint (measuring >13 mm in transverse diameter or 2 mm greater in height in the coronal plane, and presence of 3 or more 5 mm contiguous slices showing continuity of the anterior and posterior horns in the sagittal plane; **Fig. 15**).[62]

Tarsal coalitions are common abnormalities of the hindfoot. Approximately 50% of coalitions are bilateral. Talocalcaneal and calcaneonavicular coalitions are the most common tarsal coalitions. Clinically, affected pediatric patients present with recurrent sprains and minor injuries with chronic foot pain and rigidity. The pain typically worsens with increased activity.[63] However, many tarsal coalitions can be asymptomatic without peroneal spasms or pes planovalgus deformity.[64] Radiographic features of calcaneonavicular coalition include visualization of abnormal osseous or fibrocartilaginous changes between the calcaneus and navicular in a medial oblique radiograph of the foot, and elongation of the anterior process of the calcaneus in the lateral view. Dorsal beaking of the talus and a continuous C-sign can be seen in lateral radiographs in the presence of a talocalcaneal coalition.[65] CT and MR imaging are more sensitive than radiographs and can be used effectively for treatment evaluation of subtalar coalitions (**Fig. 16**).[66]

Pathologic Fractures

Pathologic fractures can be seen with both benign and malignant bone lesions. In the pediatric population, a unicameral bone cyst is a relatively common benign lesion associated with a propensity to cause pathologic fracture. The classic radiographic features of a unicameral bone cyst include a central intramedullary location with cortical thinning adjacent to the metaphysis of the proximal humerus or femur. Following a pathologic fracture, a small cortical fallen fragment can be seen radiographically as a dependent bone fragment within the central portion of the fluid filled cavity of the cystic lesion (**Fig. 17**).[67,68]

Fig. 15. A 7-year-old girl with left knee pain and locking sensation due to discoid lateral meniscus. Coronal intermediate-weighted sequence MR image at the midportion of the lateral femoral condyle shows diffuse enlargement of the lateral meniscus (*arrow*) measuring 20 mm in transverse diameter.

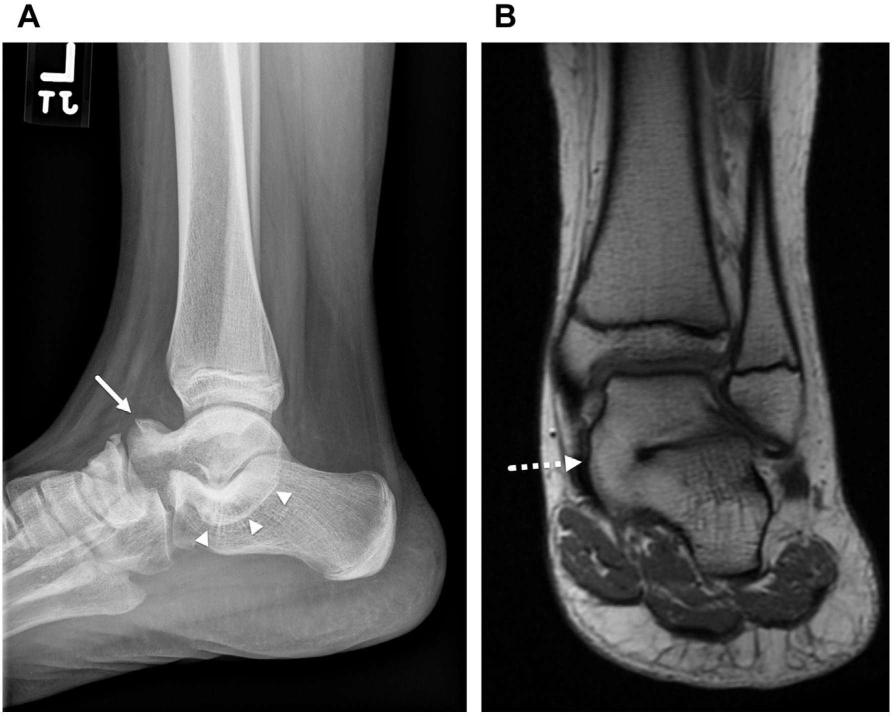

Fig. 16. Talocalcaneal coalition in a 12-year-old girl with persistent left ankle pain and cramping. (*A*) Lateral radiograph shows dorsal beaking (*arrow*) of the talus and a continuous C-sign (*arrowheads*). (*B*) Coronal T1-weighted MR image confirms complete osseous coalition (*interrupted arrow*) between the talus and calcaneus.

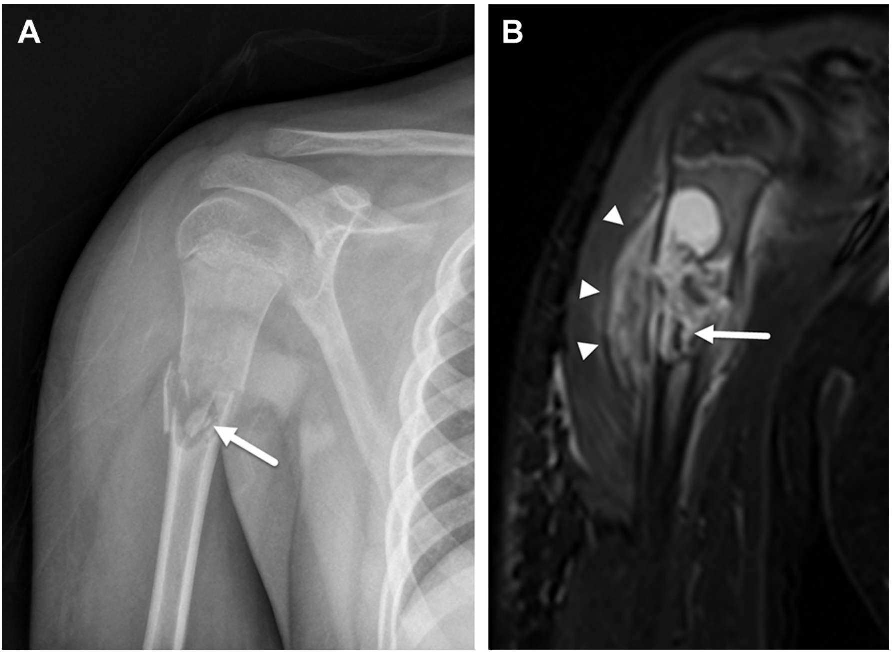

Fig. 17. A 13-year-old boy with severe right upper extremity pain after fall. (*A*) Frontal view of the right shoulder shows comminuted pathologic fracture with small cortical fragment within a cystic bone lesion (*arrow*). (*B*) Coronal STIR MR image confirms the fallen fragment (*arrow*) within a unicameral bone cyst. A pathologic fracture and subperiosteal hematoma (*arrowheads*) are also noted.

SUMMARY

Traumatic musculoskeletal injuries are a substantial source of morbidity in children and adolescents. The immature skeleton demonstrates unique injury patterns because of the presence of a growth plate and mechanical characteristics favoring plastic deformation. Clear understanding of these patterns of musculoskeletal injuries and potential for complications related to continued growth potential are essential for appropriate imaging diagnosis and optimal pediatric patient management.

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