8-1-2020

Pediatric Musculoskeletal Trauma: Special Considerations

Jessica Leschied

Steven B. Soliman

Seminars in ROENTGENOLOGY

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Jessica R Leschied, MD,* and Steven B Soliman, DO, RMSK†

Introduction

The old adage that "Children are not just small adults" is certainly true when examining pediatric musculoskeletal injury patterns on imaging. For numerous reasons, children sustaining musculoskeletal injury demonstrate unique fracture and soft tissue injury patterns that will be discussed in this chapter. Following this overview, the reader should understand the following:

- Why the different biophysical properties of children's bones result in unique fracture patterns;
- The appropriate imaging utilization for various types of pediatric musculoskeletal injury;
- A general overview of the imaging appearance of unique fracture and soft tissue injury patterns in children.

Specific fracture patterns unique to children will be discussed with occasional examples, highlighting the plastic, buckle, greenstick and complete fractures, and the Salter-Harris classification of fractures, both acute and chronic. Special attention will be paid to fractures specific to the growing skeleton such as pediatric elbow fractures, fractures around the hip, and fractures sustained in nonaccidental injury. A brief overview of select ligament injuries that may be encountered with imaging of the pediatric and adolescent patient will be covered.

Injury and the Growing Skeleton

Pediatric fractures are common, accounting for approximately 25% of pediatric emergency department and primary care visits in the United States.[1] They are typically the result of a fall on an outstretched arm, or FOOSH injury (either due to a mechanical or athletic fall) and are therefore most common in the upper extremity. Distal radius, supracondylar humerus and clavicle fractures are the most commonly sustained fractures. One in 5 children will sustain a fracture during childhood, fortunately most will heal with conservative measures.

When a child's bone fractures, it may look different on imaging than an adult fracture. First, the growing bone in its various stages of development, is less dense allowing it to absorb more energy before completely breaking. This is why we see plastic, buckle and greenstick type fractures in children. Second, children's bones are more porous which allows the bone to localize energy to one site, resulting in fewer comminuted fractures than in adults. Lastly, children's bones heal very differently, and these differences are apparent on imaging. Their bones are growing all the time, as a result of numerous vascular channels and a thick osteogenic periosteum that is not as densely adherent to the underlying bone as it is in adults. This allows for rapid and sometimes exuberant periostitis and callus formation at the site of a fracture, appearing within as little as 10 days in an infant. The younger the child, the earlier one may see signs of fracture healing on radiographs.

Imaging Utilization

Any time ionizing radiation is considered for the purposes of medical diagnosis or treatment, medical professionals must keep in mind the principle of ALARA, or pledge to use radiation doses "as low as reasonably achievable" to yield a safe and accurate outcome. This is especially relevant in children and adolescents whose developing organs and tissues are more radiosensitive than in adults.[2] All individuals working with or utilizing ionizing radiation must be aware of the principles and management of radiation dose to the patient and the surrounding personnel and readily consult resources that

*Divisions of Pediatric and Musculoskeletal Radiology, Department of Radiology, Henry Ford Health System, Detroit, MI.
†Division of Musculoskeletal Radiology, Department of Radiology, Henry Ford Health System, Detroit, MI.
Address reprint requests to Jessica R Leschied, MD, Divisions of Pediatric and Musculoskeletal Radiology, Department of Radiology, Henry Ford Health System, 2799 W. Grand Blvd, Detroit, MI 48202. E-mail: jessicale@rad.hfh.edu

https://doi.org/10.1053/j.ro.2020.07.017

explain appropriate utilization, optimization and use of dose reference levels.[3]

The typical imaging work-up for pediatric musculoskeletal trauma begins and often ends with the radiograph. The injured extremity should be imaged in 2 orthogonal planes (AP and lateral) in very young children (under 5 years of age). An additional oblique image is usually included in older children (over 5 years of age) or in special circumstances. Imaging the contralateral, or asymptomatic, extremity may prove helpful in some cases though this should be performed at the discretion or request of the radiologist or ordering physician and is not routinely included in the radiograph order set. CT and MRI are usually reserved for more complex fractures, such as various Salter-Harris fractures and their complications, or those requiring surgical management. CT or MRI may also be indicated for fractures that are suspected clinically though with initial normal radiographs. A tibia stress fracture is one such example where radiographs may be normal but if there is a high degree of suspicion in an adolescent athlete with shin pain, an MRI is warranted to make the diagnosis and guide management decisions including when to return to activity. Ultrasound is not typically performed for pediatric osseous trauma though may play a role in instances where the radiograph is negative or diagnosis is confounded by unossified growth centers.

Fracture Classification Systems

The plastic, buckle, and greenstick fractures are unique to pediatric patients and occur due to the softer growing bone. The plastic fracture is most commonly seen in the forearm and clavicle in young school-aged children and occurs when the bone bends beyond its natural capacity for elastic recoil but without causing a break in the cortex. The buckle fracture is very common and can be encountered in nearly any long bone in children. It may be challenging to detect and often discovered as a subtle cortical contour "buckle" seen only on one view. One type of buckle fracture described in young children is the buckle fracture of the proximal anterior tibial metaphysis resulting from a hyperextension injury to the knee. This has been termed the "trampoline fracture"[4] as it was originally described following a specific injury to children jumping on a trampoline alongside heavier children or adults. When the larger person lands on the trampoline bed, it results in a forceful upward recoil of the trampoline. If the smaller child lands during the recoil, a strong upward force may cause the smaller child's knee to hyperextend causing this buckling injury to the anterior tibia. This fracture is subtle on radiographs but with the appropriate injury mechanism provided, the radiologist should be careful to look for an additional cortical buckle superior to the contour of the tibial tubercle (Fig. 1). Greenstick fractures result from a stronger axial load causing a partial or incomplete fracture. Complete fractures are of course common in children and adolescents but are less commonly comminuted than in adults. The typical tibial spiral fracture is a common pediatric complete fracture.

Salter-Harris Classification

One of the most striking differences between the adult and pediatric skeleton is the presence of the growth plate, or

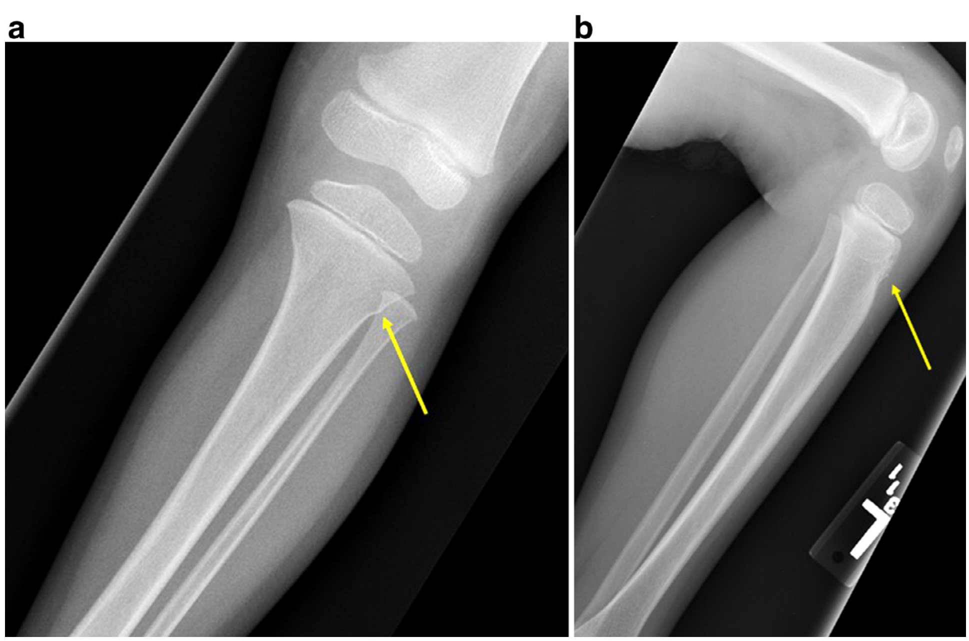

Figure 1 Four-year-old girl presents to the Emergency Department with limp and pain following play at a trampoline park. AP view (a) demonstrates lateral cortical buckle at the proximal tibia (arrow) and lateral view (b) shows the additional contour abnormality superior to the tibial tubercle (arrow) consistent with a "trampoline fracture."

physis, which histologically consists of layers of proliferating chondrocytes between the epiphysis and the metaphysis, and is responsible for contributing to endochondral, or longitudinal bone growth. The Salter-Harris classification system, which progresses in severity from I to V, describes how a fracture involves the epiphysis, physis, and metaphysis. The higher the grade of fracture, the higher the concern for damage to the physis which may have implications for healing and future growth potential.[5] The most common type is the Salter-Harris II fracture which involves the metaphysis and physis. Most of these fractures are readily detected on radiographs but occasionally may present as physeal widening that upon further inspection, additional views or magnification, demonstrate a small sliver of fractured metaphyseal bone. A specific Salter-Harris III fracture that is unique to adolescents is the juvenile Tillaux fracture. This injury results from medial rotation of the leg on a fixed foot and affects adolescents near skeletal maturity (typically girls between 12 and 14 years, and boys 12-15 years). The distal tibial growth plate fuses in a predictable manner, beginning with the central physis, then moving medially and finally to the anterolateral corner. The injury mechanism places stress on the anterior inferior tibiofibular ligament which is stronger than the unfused anterolateral physis, and results in physeal widening and a vertical fracture through the anterolateral epiphysis (Fig. 2). Once detected on radiographs or, with a negative radiograph and high degree of clinical suspicion, these injuries should be imaged with CT to assess for any degree of displacement. If displaced more than 2 mm, these fractures are typically fixed surgically with orthopedic hardware to prevent premature osteoarthritis.[6]

One type of Salter-Harris fracture that is unique to adolescents participating in high level sporting activity is the chronic stress injury to the growth plate, also known as epiphysiolysis or chronic Salter-Harris I fracture. These have been described in multiple anatomic sites and are associated with many different sporting activities but the ones most widely characterized in the literature are the proximal humerus growth plate injury in overhead throwing athletes ("Little leaguer's shoulder") and the distal radius growth plate injury ("gymnast's wrist"). Adolescent ball pitchers are most at risk of developing a chronic Salter-Harris I injury to their proximal humerus due to an accelerated phase of growth occurring at this site typically between 12 and 16 years of age.[7] Internal and external rotation AP radiographs of the humerus will show physeal widening if symptoms have been present for at least 2 weeks (Fig. 3). Comparison with contralateral views may be helpful to better detect the abnormality at the growth plate. All Salter-Harris type fractures, whether acute or chronic, can result in premature growth arrest and follow-up radiographs must be reviewed carefully for signs of asymmetric or early physeal fusion.[8]

Injury to the Hip

Another traumatic growth plate injury unique to adolescents is the slipped capital femoral epiphysis (SCFE), which is a malalignment disorder at the proximal femoral head physis

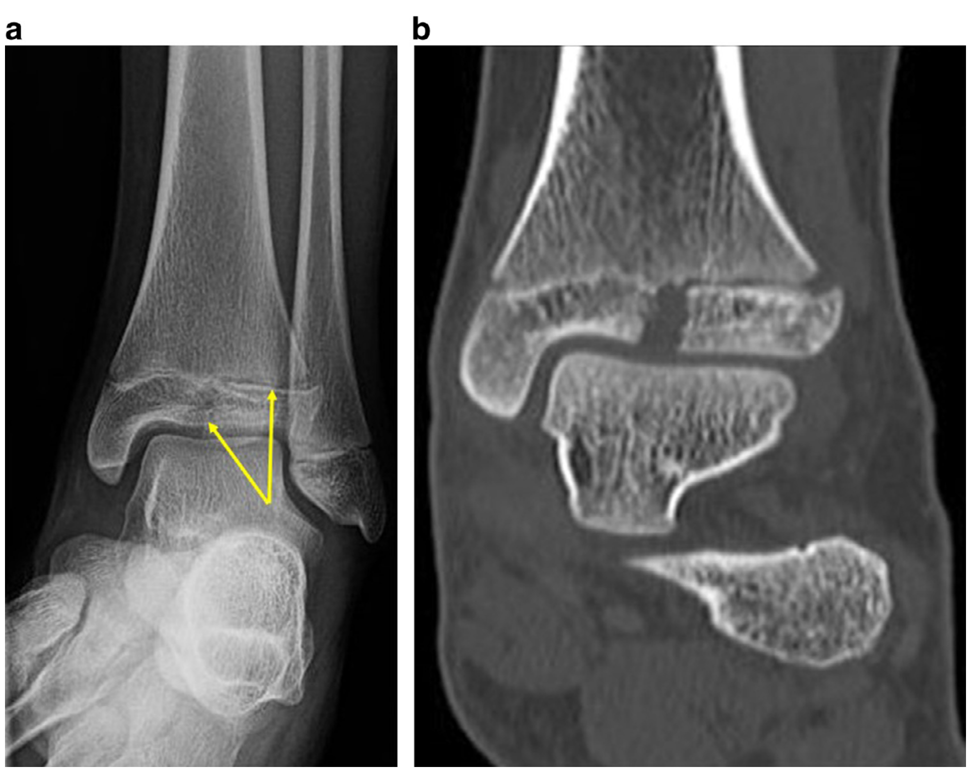

Figure 2 Thirteen-year-old boy injured while playing football. Oblique radiograph (a) demonstrates the Salter-Harris III fracture components of the juvenile Tillaux fracture (arrows) and the coronal reformatted CT image (b) for operative assessment.

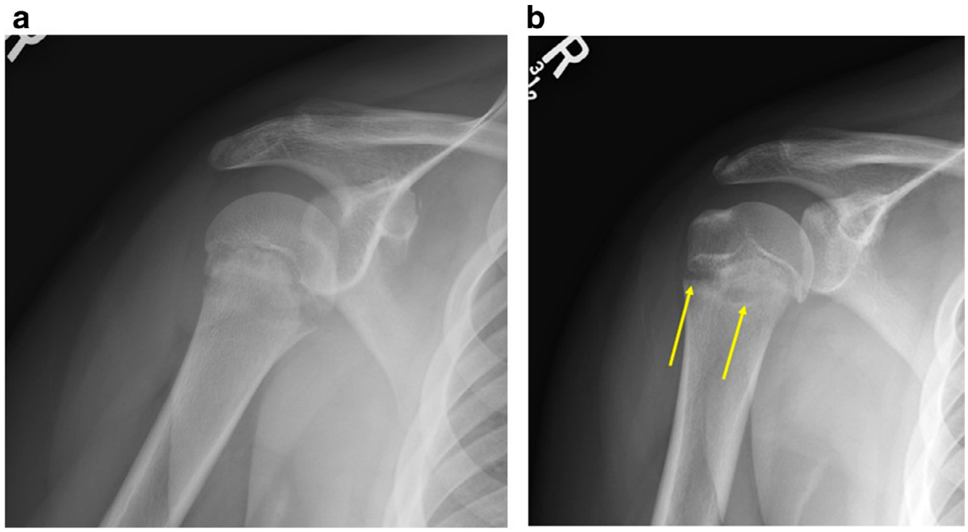

Figure 3 Internal (a) and external (b) right shoulder radiographs on a 12-year-old pitcher with insidious onset of shoulder pain demonstrating the imaging hallmark of a chronic Salter-Harris I stress injury or fracture. The arrows highlight the widened growth plate. Contralateral radiographs were not needed to make the diagnosis in this case.

resulting in posterior translation of the femoral metaphysis and anterior rotation of the epiphysis. This results in a widened appearance of the growth plate on radiographs with an offset at the femoral head-neck junction (Fig. 4), often best appreciated on the frog-leg lateral view. Initial imaging with radiographs should include an AP pelvis and bilateral frog-leg hip views, keeping in mind that 20% of patients will have a bilateral SCFE. There are different theories put forth in the literature about the pathophysiology of SCFE but it is believed to be a result of some congenital or developmental weakness at the physis that makes it susceptible to slippage or excess movement. It typically presents in the preadolescent age group (12-14 years in boys and 11-12 years in girls) with a male predominance.[9] Once detected, SCFE requires fairly urgent orthopedic surgical pinning to prevent further slippage which can increase the risk of avascular necrosis and chondrolysis.

Figure 4 AP pelvis radiograph of a 13-year-old boy with acute left hip pain demonstrates an obvious slipped capital femoral epiphysis in the left femur.

Other traumatic osseous injuries involving the pelvis and hip affecting adolescents are apophyseal avulsion fractures resulting from a chronic or acute "tug" injury at sites of tendon origin. These are common in adolescent athletes and occur due to a forced muscle contraction during athletic play, pulling off the apophysis which has a weaker attachment to the underlying osseous pelvis relative to the strength of the associated tendon. Most commonly these occur at the anterior inferior iliac spine, anterior superior iliac spine and ischial tuberosity.[10]

Elbow Fractures

The pediatric elbow is commonly injured in very young children following a FOOSH injury, accounting for 5%-10% of all pediatric fractures.[11] Fractures about the elbow can be challenging to detect on radiographs due to the 6 centers of ossification that are in various stages of ossification as a child grows. Recall the mnemonic CRITOE—which stands for capitellum, radial head, internal (medial) epicondyle, trochlea, olecranon and external (lateral) epicondyle, representing an approximate order in which the 6 elbow ossification centers appear radiographically. In addition, correctly positioning a young child to obtain a true AP and lateral radiograph adds to the challenge of detecting elbow fractures. The most common fracture around the elbow is the supracondylar humerus fracture, followed by radial neck fracture and lateral condyle fracture.[11] A helpful clue to the presence of an occult fracture are the displaced fat pads, particularly the posterior fat pad which will be elevated off the olecranon fossa when the joint capsule is distended by hemarthrosis (in the setting of trauma), fluid, or synovial proliferation. Not infrequently, more than one fracture or osseous injury can be detected in the setting of elbow trauma, as occurs with the Monteggia fracture (Fig. 5), and the occurrence of a radial neck fracture with concomitant olecranon fracture.

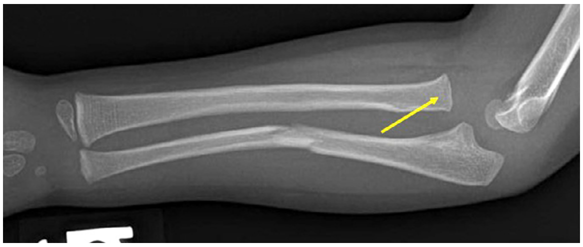

Figure 5 A Monteggia fracture in a 4-year-old boy who fell on the playground. There is an obvious mid diaphyseal ulnar fracture but in addition, the radial head (arrow) does not line up appropriately with the capitellum which confirms the presence of a radial head dislocation as well. This will need to be reduced.

Soft Tissue or Ligamentous Injury

Ulnar Collateral Ligament of the Elbow

High-level participation in some sporting activities may predispose the growing athlete to specific ligamentous injury patterns. One such example is the risk of injury to the medial elbow supporting structures in overhead throwing athletes. The primary supporting ligament of note is the anterior band of the ulnar collateral ligament (UCL) which extends from the medial epicondyle of the humerus to the sublime tubercle of the ulna.[12,13] Radiographs should be obtained as the first-line imaging modality if this injury is suspected, although these are initially normal in up to 85% of cases.[6] If the young athlete is skeletally immature, however, radiographs may

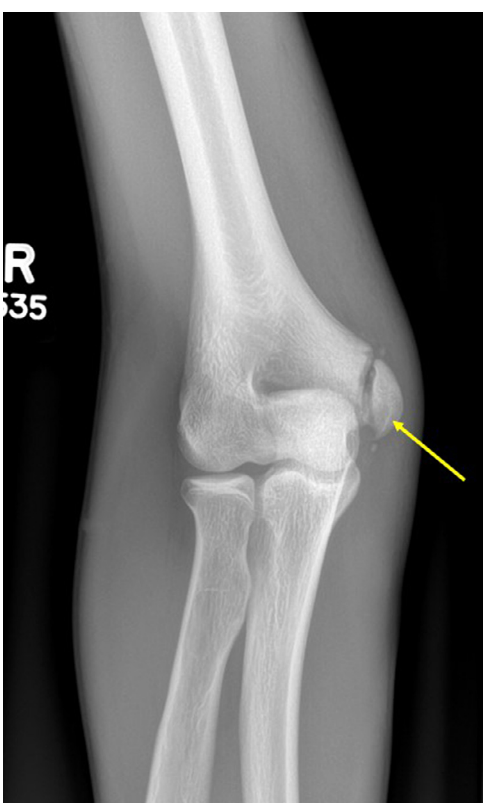

Figure 6 Chronic traction injury to the medial epicondyle (arrow) in this 14-year-old pitcher. Notice the widening of the underlying growth plate and the areas of callus formation on either side of the physis.

Figure 7 Coronal T2-weighted fat suppressed MR image of the left elbow in a 12-year-old boy with medial epicondyle traction apophysitis demonstrates the MR imaging findings of medial epicondyle (asterisk) stress injury to the physis (widened and fluid signal physis) but with a normal anterior band of the UCL (arrow). Note the relatively brighter signal proximal UCL fibers which can be normal in children.

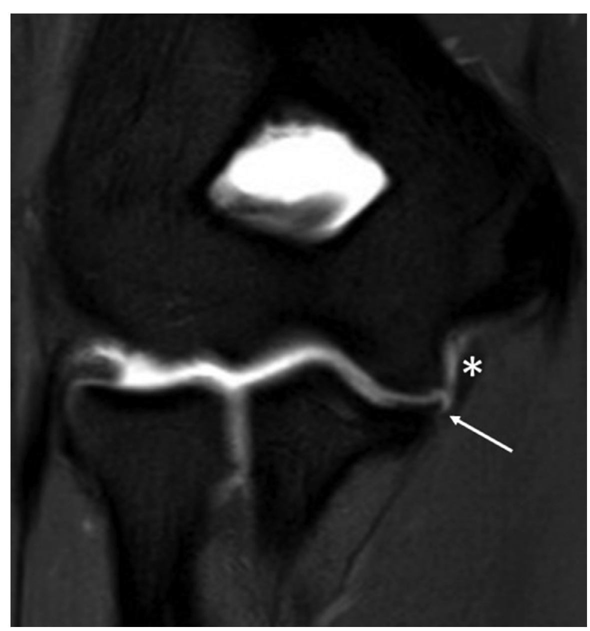

Figure 8 Coronal T1-weighted fat supressed MR arthrogram image of a 16-year-old baseball pitcher displays the anterior band of the ulnar collateral ligament (asterisk) with contrast insinuating between the undersurface of the distal ulnar attachment of the ligament (arrow) at the sublime tubercle, representing the “T sign”, compatible with an undersurface partial-thickness tear.

demonstrate other medial elbow pathology such as medial epicondyle traction apophysitis or avulsion (Fig. 6). In the skeletally mature pediatric athlete, attention should shift to imaging the UCL with MRI or ultrasound.[14]

On MRI, a full-thickness UCL tear will present as complete disruption with extravasation of joint fluid. A sprain will present as a thickened UCL with increased intrasubstance signal on fluid-sensitive sequences but no discontinuity.[13] It is important to mention that the proximal UCL in children can appear more hyperintense on T1- and T2-weighted sequences compared to the adult UCL, likely related to higher elastin and lower type I collagen content, and this should not be mistaken for pathology (Fig. 7).[14] MR arthrography can better delineate a partial-thickness tear or confirm a full-thickness tear, however is invasive and requires fluoroscopic guided injection of intra-articular gadolinium-based contrast material which may be a challenge for young patients. Partial-thickness undersurface tears at the sublime tubercle on an MR arthrogram can present with contrast material insinuating between the undersurface of the distal UCL and its remaining attachment at the sublime tubercle ("T-sign") (Fig. 8). However, in some patients the UCL may normally attach up to 3 mm distal to the articular cartilage causing a false-positive "T-sign."[13,15]

Ultrasound (US) can also be used to evaluate the UCL and allows for dynamic assessment and easy comparison to the contralateral side. US is also cheaper, time-effective, accessible, and has better spatial resolution than MRI, though is operator dependent and requires a learning curve to interpret. Children may also prefer this modality to MRI or MR arthrography as it does not require the length of time or stillness required of MRI or the invasive injection of contrast media. Typically, a high-frequency linear transducer is utilized and placed in the long-axis at the patient's medial elbow which is placed into a slightly flexed position (Fig. 9).[15,16] The normal UCL appears as a compact fibrillar hyperechoic linear structure. A ligament sprain will appear hypoechoic and thickened. A full-thickness tear will present as a complete disruption, often with intervening fluid. Dynamic US can be used to help differentiate a partial-thickness tear from a nondisplaced full-thickness tear by measuring the

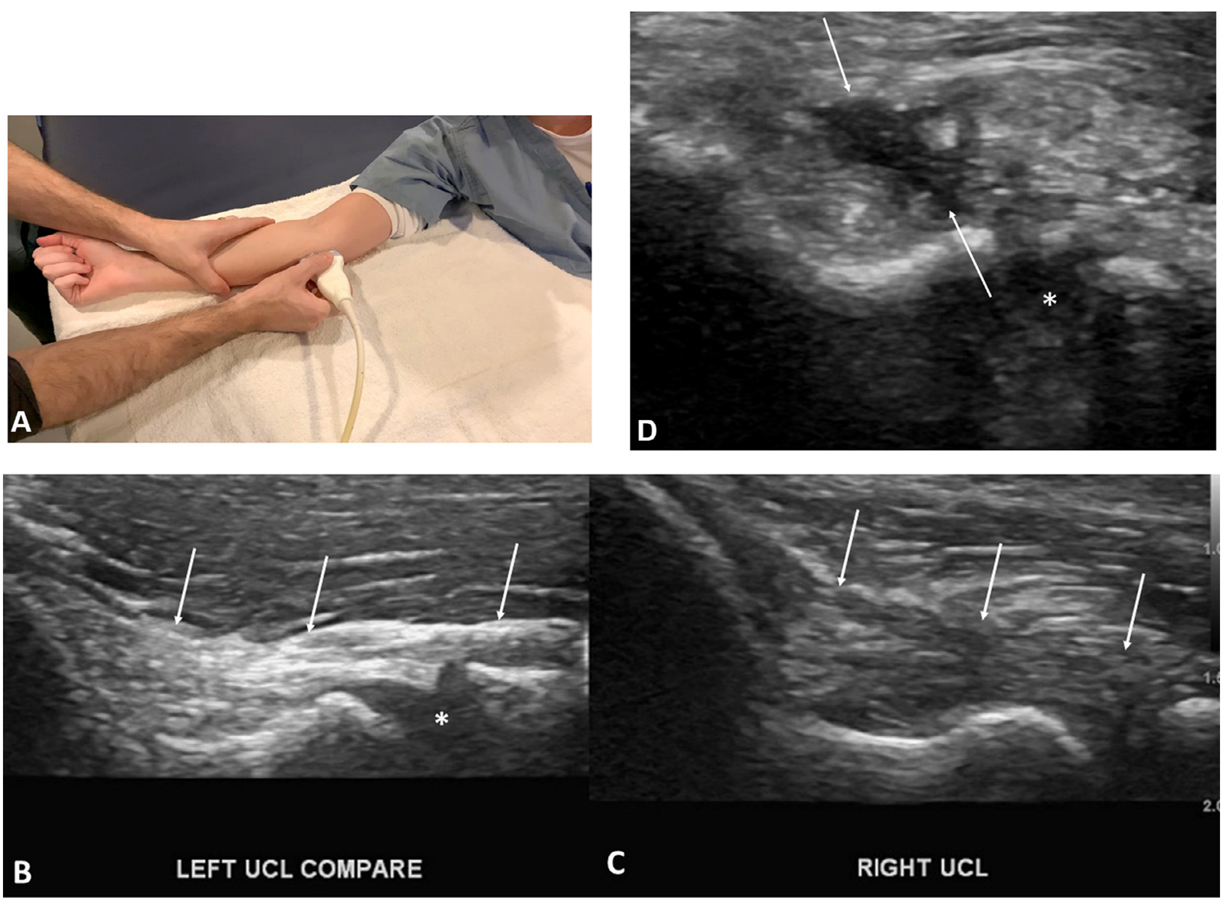

Figure 9 Suggested technique for imaging the UCL with ultrasound (a). Note the normal *left* UCL in a 15-year-old male pitcher with *right* elbow pain (b). Arrows outline the compact fibrillar hyperechoic ligament extending from the medial epicondyle to the sublime tubercle spanning the ulnotrochlear joint (asterisk). The contralateral symptomatic right ulnar collateral ligament (c) demonstrates a hypoechoic, thickened appearance (arrows) without discontinuity, consistent with a sprain injury. A full thickness UCL tear in a 17-year-old male baseball pitcher presents as a disorganized collection of hypoechoic fluid and echogenic soft tissue with a clear hypoechoic, fluid filled gap through the ligament (arrows) (d). The ulnotrochlear joint is widened (asterisk).

width of the ulnotrochlear joint at rest and compared with valgus stress.[15,16]

Anterior Cruciate Ligament

Injuries of the anterior cruciate ligament (ACL) are common in the pediatric population due to increased participation in sport activities.[17] ACL injuries are common in field sports such as football, soccer and rugby but also common in skiing accidents, motor vehicle accidents and falls.[18] The ACL is a major stabilizer of the knee and the primary restraint of anterior tibial translation and internal tibial rotation. The most common mechanism of injury is a valgus pivot-shift type injury where either the femur rotates externally in relation to a fixed tibia or the tibia rotates internally relative to a fixed femur causing contact between the lateral tibial plateau and the lateral femoral condyle.[18] Unique to the skeletally immature pediatric patient is the ACL "equivalent tear," or tibial intercondylar spine avulsion fracture. This occurs at the tibial attachment of the ACL due to the weakness of the ossifying tibial spine relative to the stronger ligament (Fig. 10).[17,18] Once the child is skeletally mature, the injury pattern is similar to adults and full-thickness ACL tears are common.[17,19] MRI is the study of choice to evaluate for an ACL injury. This allows direct visualization of the ligaments, the associated bone contusions, and the menisci, which are injured in 50% of ACL tears in young patients.[20]

The normal ACL in children will appear more attenuated than in adults, which may confound the diagnosis of injury.[18] An acutely torn ACL will be ill-defined, edematous and discontinuous and with high intrasubstance signal on fluid-sensitive sequences. An acute rupture will be accompanied by a joint effusion or lipohemarthrosis, and the classic pattern of bone contusions at the lateral femoral condyle and posterior lateral tibial plateau. Given the more widespread use of musculoskeletal US, it is not unusual for an US of the knee to precede or replace an MRI in the evaluation of knee pain or swelling.[21] Sonographic findings of an ACL tear have been described[22] but the technical details are beyond the scope of this review article. Succinctly, a posterior approach can be used to evaluate the lateral wall of the femoral intercondylar notch for a hypoechoic collection (hematoma) displacing the normally echogenic intercondylar fat at the expected ACL femur attachment.

Ligament Injuries of the Ankle

Injuries of the lateral ankle ligamentous complex are the most common ankle soft tissue injury in pediatric athletes with the anterior talofibular ligament (ATFL) the most commonly injured ligament.[23] Typical culprit sports include gymnastics, basketball, football, soccer and cheerleading. US and MRI have both shown greater than 90% accuracy in the diagnosis of ATFL. The normal ATFL has a compact taut echogenic fibrillar appearance. Ligament thickening, a hypoechoic appearance and adjacent fluid are all signs of an injured ATFL (Fig. 11).[23,24] Similar to other ligament attachments in the skeletally immature patient, the fibular physis serves as a structural weakness and therefore, the distal fibula is more commonly injured than the attached ATFL as a

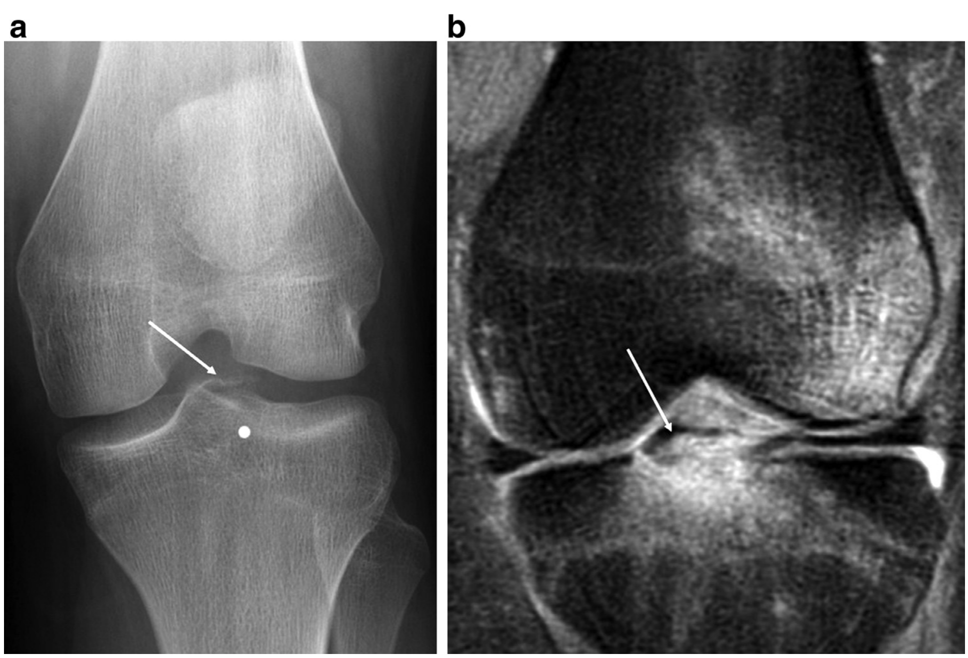

Figure 10 Radiographic and MR imaging of the left knee in a 16-year-old boy presenting with pain after football injury. Anteroposterior radiograph (a) demonstrates an avulsion fracture (arrow) at the ACL attachment at the tibial spine (metallic BB marker placed over site of pain by radiographer). Coronal T2-weighted fat saturated (b) MR image confirms the tibial spine avulsion (arrow) with underlying marrow edema.

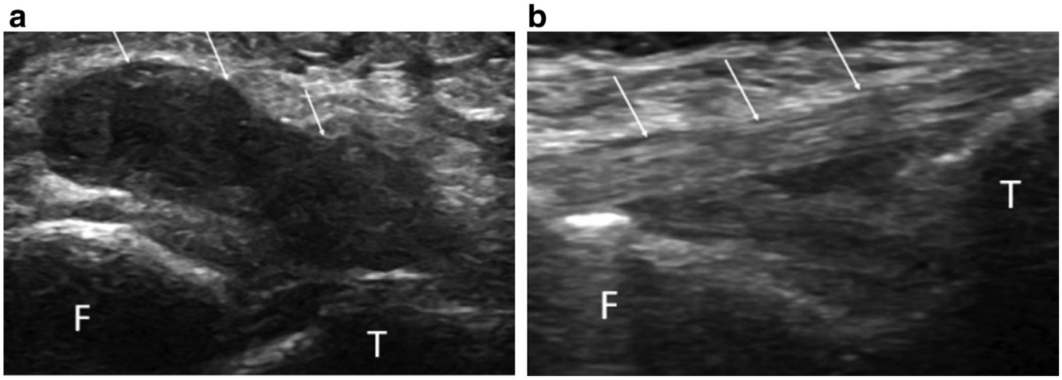

Figure 11 Long-axis sonographic image of the lateral right ankle of 17-year-old boy following a soccer injury (a). A full-thickness tear of the anterior talofibular ligament presents as a complex hypoechoic fluid collection (arrows) in the expected location of the normal ligament. Normal ATFL (arrows) for comparison in a 9-year-old boy (b). F, fibula; T, talus.

consequence of incomplete ossification.[24] Avulsions of the fibular epiphysis can be diagnosed on radiographs but subtle fractures can often be radiographically occult. In at least one study, US demonstrated a greater sensitivity for subtle avulsion fractures and given its additional utility in diagnosing soft tissue injury, it could be considered as the modality of choice for pediatric injuries of the lateral ankle, both osseous and ligamentous.[24]

Nonaccidental Trauma

Nonaccidental trauma (NAT) requires special mention in this review article on pediatric musculoskeletal injury. A more extensive discussion of the injuries that can be seen with NAT is beyond of the scope of this article and should be reviewed by the reader elsewhere.[25-28]

Fractures are the second most common injury described in NAT, behind skin injuries such as bruises and abrasions.[25] Fractures that are highly specific for NAT include the classic metaphyseal fracture (bucket handle fracture or corner fracture) (Fig. 12), rib fractures and avulsion fractures at the clavicle and acromion.[29] Other fractures that are highly suggestive of child abuse when inconsistent with the age of the child and reported mechanism of injury, are the presence of multiple fractures, fractures of differing ages, and long bone fractures (radius, ulna, tibia, fibula, and femur) in children <1 year of age.[29]

The skeletal survey should be the first imaging study performed if there is a clinical suspicion for child abuse in a child under the age of 2 years. Beyond the age of 2 years, skeletal imaging should be focused to the anatomic location of injuries detected by history and physical examination, unless there are factors that confound the accuracy of physical examination, such as developmental delay. There are specific guidelines for how to perform the skeletal survey that are endorsed by the American College of Radiology and the Society of Pediatric Radiology (Table 1).[27] Ideally, the skeletal survey should be checked by the interpreting radiologist with some familiarity with the technique prior to removing the child from the radiology department, to ensure all appropriate images have been performed and to obtain additional images or views, if needed. A follow-up skeletal survey should be performed in 2 weeks if there is a high clinical suspicion for child abuse even with a negative initial survey, or if there are positive or equivocal findings on the initial survey.[30]

Figure 12 Right ankle image in a young child (age unknown) presenting with skeletal survey findings of nonaccidental trauma including this subacute or healing classic metaphyseal fracture (arrow) of the distal tibia.

Table 1 Imaging Guidelines for Skeletal Survey in Suspected NAT

Axial Skeleton	Appendicular Skeleton
Thorax (AP, lateral, right, and left obliques) to include sternum, ribs, thoracic, and upper lumbar spine	Humeri (AP)
Abdomen (AP to include pelvis)	Radii and ulnae (AP)
Lumbosacral spine (lateral)	Hands (AP)
Skull (frontal and lateral—include cervical spine on lateral)	Femurs (AP)
	Tibiae and fibulae (AP)
	Feet (AP)

Conclusion

Injury to the growing skeleton and surrounding soft tissue supporting structures will manifest differently on imaging than the skeletally mature patient. It is important for the general radiologist to be familiar with commonly sustained fractures in the pediatric patient, how they appear on radiographs, and when to suggest additional imaging including CT, MRI, or US to the referring providers. Awareness of the specific fracture patterns described in nonaccidental trauma is paramount to any practicing radiologist's skill set, as detection of those fractures may ultimately save a child's life.

References

1. Naranje SM, Erali RA, Warner Jr. WC, et al: Epidemiology of pediatric fractures presenting to emergency departments in the United States. J Pediatr Orthop 36:e45-e48, 2016
2. Kutanzi KR, Lumen A, Koturbash I, et al: Pediatric exposures to ionizing radiation: Carcinogenic considerations. Int J Environ Res Public Health 13:1057, 2016
3. American College of Radiology, ACR-AAPM technical standard for diagnostic medical physics performance monitoring of radiographic equipment, 2016; Available at https://www.acr.org/-/media/ACR/Files/Practice-Parameters/RadEquip.pdf. Accessed August 3, 2020.
4. Boyer RS, Jaffe RB, Nixon GW, et al: Trampoline fracture of the proximal tibia in children. AJR Am J Roentgenol 146:83-85, 1986
5. Cottalorda J, Béranger V, Louahem D, et al: Salter-Harris type III and IV medial malleolar fractures: Growth arrest: Is it a fate? A retrospective study of 48 cases with open reduction. J Pediatr Orthop 28:652-655, 2008
6. Santos-Pereira R, Aleixo C, Oliveira M, et al: Painful nonunion after missed juvenile tillaux fracture in an athlete - case report and description of a new fixation technique. J Orthop Case Rep 8:7-10, 2018
7. Fleming JL, Hollingsworth CL, Squire DL, et al: Little Leaguer's shoulder. Skelet Radiol 33:352-354, 2004
8. Caine D, DiFiori J, Maffulli N: Physeal injuries in children's and youth sports: Reasons for concern? Br J Sports Med 40:749-760, 2006
9. Novais EN, Millis MB: Slipped capital femoral epiphysis: Prevalence, pathogenesis, and natural history. Clin Orthop Related Res® 470:3432-3438, 2012
10. Calderazzi F, Nosenzo A, Galavotti C, et al: Apophyseal avulsion fractures of the pelvis. A review. Acta Bio Medica Atenei Parmensis 89:470-476, 2018
11. Emery KH, Zingula SN, Anton CG, et al: Pediatric elbow fractures: A new angle on an old topic. Pediatr Radiol 46:61-66, 2016
12. Andelman S, DiPrinzio E, Hausman M: Elbow injuries in the pediatric athlete. Ann Joint 3, 2018
13. Davis KW: Imaging pediatric sports injuries: Upper extremity. Radiol Clin North Am 48:1199-1211, 2010
14. Delgado J, Jaramillo D, Chauvin NA: Imaging the injured pediatric athlete: Upper extremity. Radiographics 36:1672-1687, 2016
15. Bucknor M, Stevens K, Steinbach L: Elbow imaging in sport: Sports imaging series. Radiology 280:328, 2016
16. Roedl JB, Gonzalez FM, Zoga AC, et al: Potential utility of a combined approach with US and MR arthrography to image medial elbow pain in baseball players. Radiology 280:328, 2016
17. O'Dell MC, Jaramillo D, Bancroft L, et al: Imaging of sports-related injuries of the lower extremity in pediatric patients. Radiographics 36:1807-1827, 2016
18. Jaremko JL, Guenther ZD, Jans LBO, et al: Spectrum of injuries associated with paediatric ACL tears: An MRI pictorial review. Insights Imaging 4:273-285, 2013
19. Prince JS, Laor T, Bean JA: MRI of anterior cruciate ligament injuries and associated findings in the pediatric knee: Changes with skeletal maturation. AJR Am J Roentgenol 185:756-762, 2005
20. Dumont GD, Hogue GD, Padalecki JR, et al: Meniscal and chondral injuries associated with pediatric anterior cruciate ligament tears: Relationship of treatment time and patient-specific factors. Am J Sports Med 40:2128-2133, 2012
21. Mallon S, Bussis K, Beswick Z, et al: Ultrasonographic and radiographic findings of polyethylene component displacement with severe metallosis and metal-induced synovitis following total knee arthroplasty. Knee 26:941-950, 2019
22. Ptasznik R, Feller J, Bartlett J, et al: The value of sonography in the diagnosis of traumatic rupture of the anterior cruciate ligament of the knee. AJR Am J Roentgenol 164:1461-1463, 1995
23. Spicer PJ, Fain AD, Soliman SB: Ultrasound in Sports Medicine. Radiol Clin North Am 57:649-656, 2019
24. Szczepaniak J, Ciszkowska-Łysoń B, Śmigielski R, et al: Value of ultrasonography in assessment of recent injury of anterior talofibular ligament in children. J Ultrason 15:259-266, 2015
25. Nguyen A, Hart R: Imaging of non-accidental injury; what is clinical best practice? J Med Radiat Sci 65:123-130, 2018
26. Paine CW, Scribano PV, Localio R, et al: Development of guidelines for skeletal survey in young children with intracranial hemorrhage. Pediatrics 137:e20153024, 2016
27. van Rijn RR, Sieswerda-Hoogendoorn T: Educational paper: Imaging child abuse: The bare bones. Eur J Pediatr 171:215-224, 2012
28. Pfeifer CM, Hammer MR, Mangona KL, et al: Non-accidental trauma: The role of radiology. Emerg Radiol 24:207-213, 2017
29. Meyer JS, Gunderman R, Coley BD, et al: ACR Appropriateness criteria((R)) on suspected physical abuse-child. J Am Coll Radiol 8:87-94, 2011
30. Section of Radiology, American Academy of Pediatrics: Diagnostic imaging of child abuse. Pediatrics 123:1430-1435, 2009