Frequently Missed Fractures in Pediatric Trauma

A Pictorial Review of Plain Film Radiography

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KEYWORDS

• Pediatric • Radiology • Fracture • Missed • Emergency • Radiography

KEY POINTS

- Missed fractures are common in pediatric patients because of the subtlety of findings, significant normal variation in the developing skeleton, and unique site-specific fracture patterns found only in children.
- Bones in children are distinguished by increased elasticity and porosity, the relative strength of the periosteum, and the vulnerability of the physis compared with bones in adults.
- Unique fracture types of the pediatric skeleton include torus or "buckle" fractures, plastic bowing and greenstick fractures, and physeal injury.
- Pediatric fractures are subtle. Understanding the mechanism and common patterns of site-specific injuries facilitates detection.

INTRODUCTION

Missed fractures are common in pediatric trauma patients. Fractures in children differ substantially from those in adults, because injuries may be subtle or even radiographically occult. Additionally, there is substantial variation in the contour of developing bones and the growth plate, such that normal findings may sometimes mimic injury. When left undiagnosed, untreated fractures can have serious cosmetic and functional consequences in children.[1] They are also the most common cause of medicolegal complications for pediatric trauma physicians, emergency room physicians, and radiologists.[2,3]

Understanding the mechanism and radiographic appearance of pediatric skeletal trauma facilitates detection of these injuries, which results in better outcomes for patients. This article examines the unique features of pediatric bone contributing to missed fractures, the incidence of missed fractures, common injury types of the pediatric skeleton, and frequently missed site-specific fracture patterns, highlighting problem-solving techniques for challenging cases.

UNIQUE FACTORS OF PEDIATRIC BONE

It is an axiom of pediatric medicine that "children are not just small adults." This is also true of the immature skeleton. In adults, when a force is applied to a mature bone, the force propagates through the bone because of its rigidity, until the point of fracture, which manifests as a cortical discontinuity. Children have proportionately more cartilage and collagen than the adult skeleton and their bones are thus less rigid.[4] The increased elasticity and porosity of immature bone leads to a higher likelihood of fracture,[5] although the fracture is less likely to propagate. Furthermore, the outer periosteal sleeve of a child's bone is proportionally tougher than the inner fibrous cortex. As such

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pediatric fractures may demonstrate cortical deformity rather than discontinuity (the torus or "buckle" fracture).

The physis adds an element of complexity to the pediatric skeleton. This highly vascular structure is the site of longitudinal and transverse growth of long bones and manifests radiographically as a straight or undulating lucent band. Histologically, the physis is composed of resting, proliferating, and hypertrophying chondrocytes that undergo provisional calcification before being incorporated into the ossified metaphysis.[6] The physis is surrounded peripherally by the tough fibrous ring of Lacroix, which connects the epiphyseal and metaphyseal periosteum.[7] Because the periosteum at the level of metaphysis is weaker than the ring of Lacroix and epiphyseal periosteum,[8] fractures through the growth plate tend to deviate through the metaphysis (Salter-Harris II injury). Overall, physeal cartilage is the weakest structure in a child's skeleton.[9]

INCIDENCE OF MISSED FRACTURES IN PEDIATRIC TRAUMA

Musculoskeletal injuries comprise most occult injuries in the setting of trauma.[10] A review of the orthopedic and surgical trauma literature suggests that missed fractures are common, with retrospective studies demonstrating an incidence of between 2% and 9%,[11,12] and prospective studies showing higher rates of injury (11%–27%).[1,13] Unfortunately, most of these studies do not distinguish occult from missed fractures; and those studies that focus on missed fractures are retrospective in nature, comparing preliminary interpretations by radiology residents or nonradiologists with the gold standard of the finalized report. In such studies, the most frequently missed pediatric fractures are those of the fingers, distal radius, elbow, and proximal fibula.[14,15] Further prospective studies are needed to adequately characterize the true incidence and distribution of missed fractures in pediatric trauma.

Fig. 1. A 4-year-old girl with buckle fracture of the distal radius (*arrow*) after fall.

UNIQUE FRACTURE TYPES OF THE PEDIATRIC SKELETON

Torus Fractures

Torus or "buckle" fractures are common in the pediatric population. These fractures most frequently involve the distal radius and ulna,[4] although they are frequently missed in the small bones of the hands and feet. The mechanism of the buckle fracture is an axial load, most often on an outstretched hand. There is focal convexity on the compression side of the bone and the tension side of the bone remains intact (**Fig. 1**).[16]

One notable variant of the classic torus fracture is the angled buckle, in which a primary axial and additional secondary force is applied to the bone. In this setting, the cortex does not bulge convexly, but angles sharply inward in the direction of the secondary force (**Fig. 2**).[17] These fractures occur most frequently through the metaphysis of the proximal radius, distal tibial, and distal humerus.

Both classic and angled buckle fractures are stable, treated conservatively with immobilization, and typically heal without complication.[18]

Plastic and Greenstick Fractures

Plastic or "bowing" fractures also result from excessive axial loading. In these fractures, the elasticity of immature bone permits increased curvature over the full length of the shaft, without cortical discontinuity or offset (**Fig. 3**).[19] These fractures most commonly occur in the radius, ulna, and clavicle.[20] Subtle plastic fracture may sometimes mimic physiologic bowing, but are easily distinguished with comparison views.[21] Although considered stable injuries, some authors advocate reduction of plastic fractures when the degree of angulation exceeds 20°, or if the bowing is cosmetically unacceptable.[22]

At some point, axial loading exceeds the elasticity of the immature bone, which fractures along the tensile side of the shaft, leaving the compressive side intact (**Fig. 4**). This a greenstick fracture. Unlike plastic fractures, greenstick injuries are unstable, and frequently displace even after splinting.[23]

Physeal Fractures

Salter-Harris I and II injuries are the most frequently missed growth plate fractures because of their subtlety. Salter-Harris I injuries result from shearing

Fig. 2. A 17-year-old boy with angled buckle fracture of the distal left radius after a fall (*arrow*).

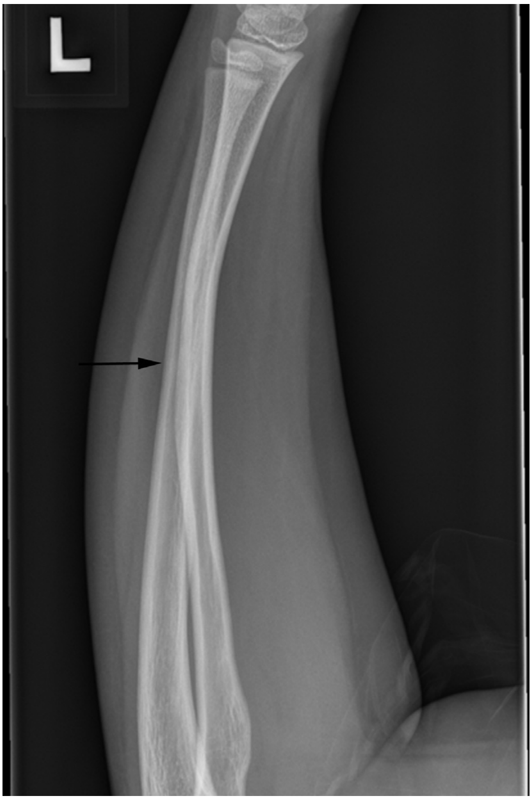

Fig. 3. An 11-year-old boy with bowing fractures of left radius and ulna (*arrow*) after fall.

Fig. 4. A 5-year-old boy with greenstick fracture of the distal ulnar shaft (*arrow*) after fall.

Fig. 5. Anteroposterior (AP) radiograph of the knee in an 8-year-old girl with a Salter I fracture of the distal femur demonstrates widening of the distal femoral physis (*arrows*).

forces applied to the physis, with the fracture plane passing exclusively through the growth plate.[24] Although offset of the metaphysis and epiphysis is easily recognizable, physeal widening may be the only sign of injury in some cases of Salter-Harris I fracture (**Fig. 5**). Comparison views are confirmatory when physeal widening is suspected,[21] because growth plate closure is typically symmetric. By contrast, Salter-Harris II injuries result from shear and angular forces, and deviate through the metaphysis (**Fig. 6**). The metaphyseal component may be subtle. A helpful sign in this setting is a bone fragment along the most distal aspect of the metaphysis (Thurston-Holland fragment) indicating metaphyseal involvement.[25] Finally, it is worth mentioning that physeal injury is often overlooked in older children, in whom the growth plate may nearly be fused. In this setting, the only suggestion of injury may be asymmetric sclerosis along the developing physeal scar.[26]

SPECIFIC PEDIATRIC FRACTURES PATTERNS THAT ARE FREQUENTLY MISSED

Shoulder and Clavicle

Coracoid process fractures are uncommon, but easily missed injuries resulting from a direct impact to the coracoid process secondary ossification center, typically during a contact sport (50%).[27,28] Fracture typically takes place at the base of the coracoid process,[29] in which the secondary ossification center is avulsed from the physis by the blow (Salter-Harris I injury). This manifests radiographically as widening of the coracoid growth plate (**Fig. 7**), best appreciated on the axillary view.[29] There is no standard management of coracoid process fractures.[30]

Little leaguer shoulder is an overuse injury of the proximal humeral physis that typically manifests in baseball pitchers aged 11 to 16 years.[31] Repeated overhead throwing motions damage the vessels within the metaphysis, altering the pattern of new bone mineralization at the provisional zone of calcification. This manifests radiographically as a widened and sclerotic physis (**Fig. 8**). Prompt diagnosis is critical, because bone bridges may develop without appropriate cessation of activity.[30]

So-called sternoclavicular (SC) dislocation is typically a Salter-Harris fracture at the level of the proximal clavicular physis. These injuries require significant compressive force to the sternum or clavicle, typically in the setting of motor vehicle collision.[32] The proximal clavicular physis, which does not close until 23 to 25 years, is the weakest

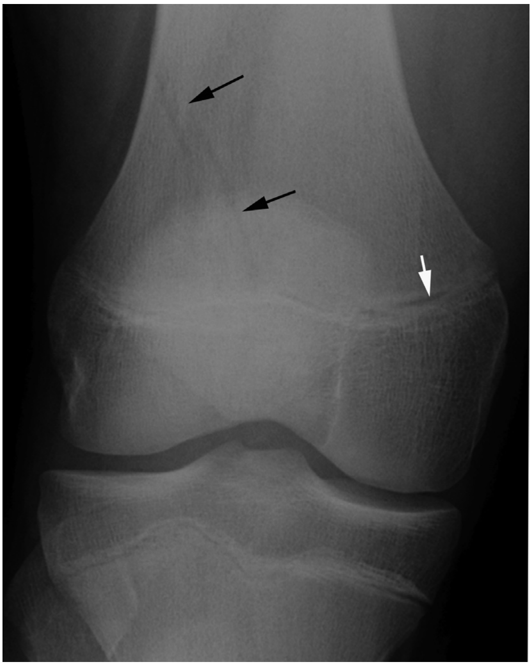

Fig. 6. AP radiograph in a 15-year-old boy with knee pain after trauma demonstrates an oblique fracture through the distal femoral metaphysis (*black arrows*) and widening of the medial physis (*white arrow*) consistent with a Salter II fracture.

component of the SC unit and fracture typically occurs through the physis.[26] Radiographic signs of clavicular physeal injury (or true SC dislocation) are subtle, and are suggested by asymmetric clavicular height (**Fig. 9**). Specifically, on a frontal radiograph, the difference in the craniocaudal positions of the medial clavicles should be less than 50% of the width of the clavicular heads.[26] If abnormal, cross-sectional imaging is recommended to distinguish Salter-Harris injury from SC

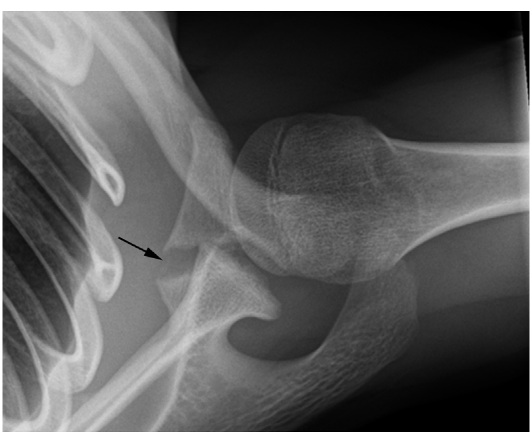

Fig. 7. A 14-year-old boy with coracoid process fracture (*arrow*).

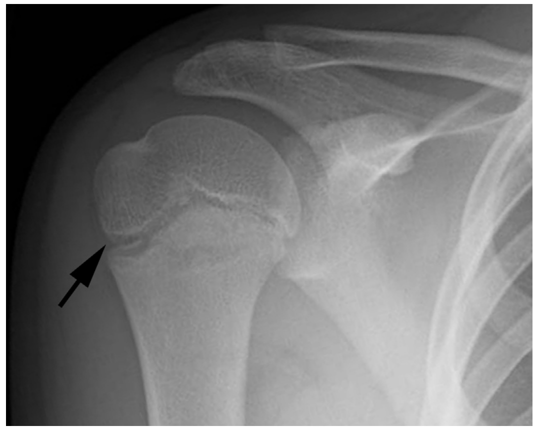

Fig. 8. A 13-year-old boy baseball pitcher with little leaguer shoulder. The proximal humeral physis is widened and irregular (*arrow*).

dislocation and assess for mediastinal complications, which are frequent.

Elbow

Supracondylar fractures are the most common elbow fracture in children. During a fall on an outstretched hand, exaggerated hyperextension displaces the ulnar olecranon into the dorsal humeral metaphyseal plate,[33] and the olecranon acts as the fulcrum of supracondylar fracture. Radiographically, the fracture manifests as transversely oriented supracondylar radiolucency (**Fig. 10**). Associated dorsal displacement disrupts the anterior humeral line, which normally passes through the posterior third of the capitellum,[34] although this finding is less sensitive in children younger than 4 years old.[35] Fractures are often subtle and a joint effusion may be the only radiographic sign of injury,[36] with elevation of posterior fat pad (**Fig. 11**). Because the anterior humeral line and fat pad are detected on the lateral radiograph, patient positioning is crucial. A good rule of thumb is that on a properly positioned lateral radiograph, a supracondylar “teardrop” should be formed by the anterior concavity of the coronoid fossa and the posterior concavity of the olecranon fossa.[36]

Radial neck fractures were considered rare, but a recent study by Emery and colleagues[37] suggests that these may be the second most common fractures of the pediatric elbow. Radial neck fractures are most commonly buckle injuries that result from hyperextension in the setting of an additional valgus force. These deformities are often subtle (**Fig. 12**) and comparison views may be necessary. They are frequently associated with olecranon fractures, which are the most common occult elbow fracture in children (**Fig. 13**).[37]

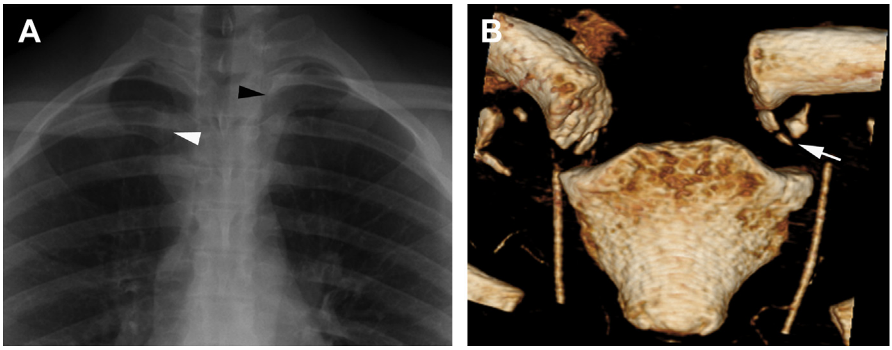

Fig. 9. (*A*) A 17-year-old boy with concern for sternoclavicular dislocation after trauma. The left clavicular head (*black arrowhead*) is asymmetric and projects higher than the right (*white arrowhead*). (*B*) Three-dimensional reconstruction from a computed tomography scan demonstrating a Salter II fracture through the proximal left clavicle on same patient, with the epiphysis and small metaphyseal fragment (*arrow*) maintaining alignment with sternoclavicular joint with superior displacement of the left clavicle.

Lateral condyle fractures are historically described as the second most common elbow fracture in children. These fractures result from a varus force on an extended elbow.[30] These fractures are easily missed, because they often primarily involve cartilaginous injury to the intercondylar region or capitellum, with only a slender bony fragment along the lateral condyle (Fig. 14). These injuries are often occult on the anteroposterior view, and an external oblique view may be necessary for confirmation.[33]

Medial epicondyle avulsions are considered the third most common pediatric elbow fracture, and typically occur in older children. The mechanism is typically a fall on an outstretched hand, combining hyperextension with valgus stress.[33] They may also occur in the setting of posterior elbow dislocation. The degree of avulsion varies from subtle widening of the medial epicondylar physis to intra-articular displacement, in which the displaced medial epicondyle mimics a trochlear ossification center (Fig. 15). For this reason, whenever "trochlear" ossification is noted, an orthotopic position of the medial epicondyle should be confirmed. It is

Fig. 10. AP radiograph of the elbow in a 20-month-old boy after a fall demonstrates a nondisplaced supracondylar fracture (*arrows*).

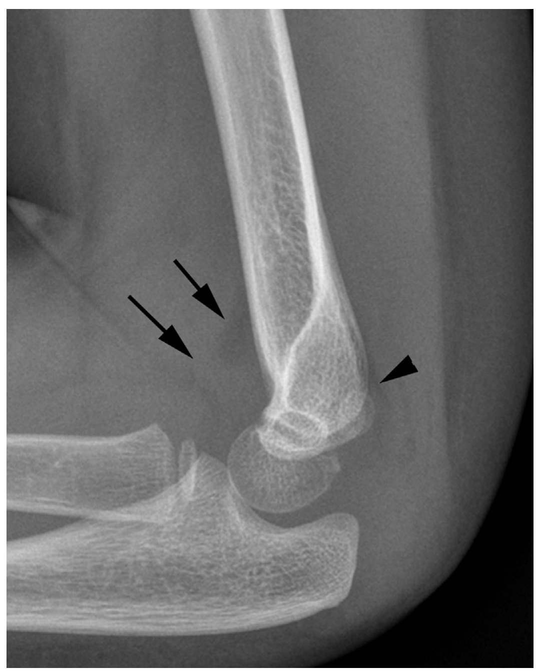

Fig. 11. Lateral radiograph of the elbow in a 4-year-old girl after fall demonstrates elevation of the anterior fat pad (*arrows*) and posterior fat pad (*arrowhead*) indicating joint effusion.

Fig. 12. Oblique radiograph of the elbow in a 4-year-old girl with pain 2 weeks after a fall demonstrates a nondisplaced radial neck (*arrow*) with subtle periosteal new bone formation).

also worth noting that, unlike supracondylar and lateral condylar fractures, injuries of the medial epicondyle can occur without a joint effusion.[36]

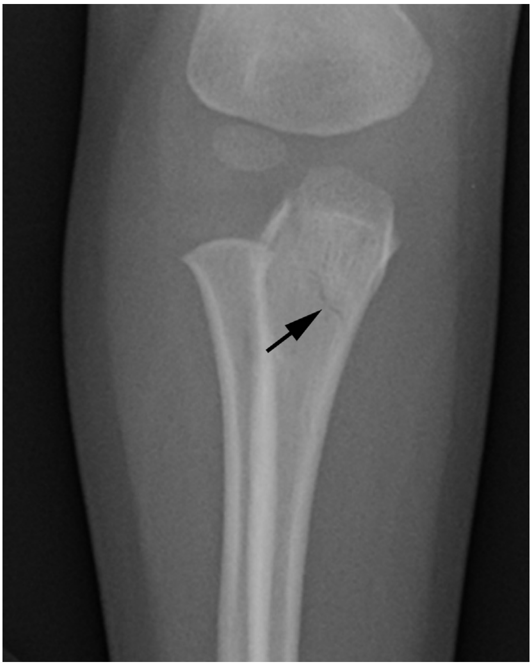

Fig. 13. AP radiograph of the elbow in a 32 month old with a nondisplaced olecranon fracture (*arrow*).

Fig. 14. AP radiograph in a 7-year-old boy with a lateral condylar fracture (*arrow*) of the elbow.

Epiphyseal separation of the distal humerus is a rare but frequently missed (56%) Salter-Harris I fracture in young children and infants.[37] In infants, the cause is typically obstetric, but in younger children the injury raises concern for nonaccidental trauma. Radiographs most frequently demonstrate medial (93%) and posterior displacement of nonossified distal humeral epiphysis, radius, and ulna (**Fig. 16**). Confirmatory ultrasound is performed in difficult cases.

Wrist

Scaphoid bone impaction fractures are frequently missed buckle fractures that result from axial loading of the wrist during hyperextension. In children, scaphoid bone fractures often demonstrate shortening or contour deformity of the scaphoid (**Fig. 17**), sometimes with a thin dense band representing superimposition of trabecula. Loss of the navicular fat pad is another subtle sign of injury.[21] Given the substantial variation in the normal appearance of the scaphoid, comparison views are often helpful.

Hip and Pelvis

Slipped capital femoral epiphysis (SCFE) is the most common abnormality of the hip in adolescence.[38] It most commonly results from repetitive microtrauma to the developing femoral neck, often during growth spurts, with predisposing

Fig. 15. AP radiograph of the elbow in an 11-year-old boy with a medial epicondylar avulsion fracture demonstrates the displaced epicondyle within the joint space (*arrow*) mimicking a trochlear ossification center. Lateral radial head subluxation is also noted.

Fig. 16. AP radiograph of the elbow in an 11-day-old girl refusing to move the right arm demonstrates medial displacement of the proximal ulna and radius with respect to the distal humerus. Epiphyseal separation at the distal humerus was confirmed with ultrasound.

factors including hypothyroidism, hypopituitarism, hyperparathyroidism, obesity, and renal osteodystrophy.[39] SCFE is a Salter-Harris I fracture of the femoral neck. Muscular insertions below the great trochanter cause the femoral metaphysis to migrate anteriorly, laterally, and superiorly, causing the appearance of "epiphyseal" slippage. This is detected on AP radiographs by disruption of Klein's line and epiphyseal foreshortening. Performing a frog-lateral view increases the sensitivity of radiographs, although this risks worsening the slip in unstable (nonambulatory) SCFE (**Fig. 18**).[40]

SCFE is rarely missed in the setting of significant metaphyseal offset. However, it is more challenging to detect the preslip phase of SCFE, in which the epiphysis and metaphysis align. It is important to emphasize that early detection can have a profound impact on the patient's prognosis. Findings of preslip SCFE include physeal widening and demineralization.[39] Early or subtle SCFE can also be easily missed, because up to 60% of cases may present with a preserved Klein's line. The sensitivity of the AP radiograph is increased by comparing the width of the epiphyses lateral to Klein's line, with a greater than 2 mm discrepancy suggestive of SCFE.[41]

Pelvic avulsion fractures are common injuries in adolescents and young adults, and reflect the relative vulnerability of the pelvic apophyses in the setting of forceful myotendinous contraction.[42] Acutely avulsed fragments are sharply demarcated, displaced along the path of their myotendinous unit, and with time become more sclerotic and ill-defined.[43] Nondisplaced avulsions are easily missed because the apophyses normally demonstrate a lucent physis. As such, any asymmetry of the pelvic apophyses should be treated with suspicion. Subacute or chronic avulsions can stimulate an aggressive periosteal reaction, mimicking osteomyelitis or malignancy.[44]

Knee

Tibial tubercle avulsion fractures occur secondary to forceful traction of the quadriceps during extension, frequently during jumping sports. They are most

Fig. 17. Oblique radiograph of the wrist in a 9 year old with wrist pain after fall demonstrates mild buckling of the radial cortex of the scaphoid bone (*arrow*) at the site of a distal pole scaphoid fracture.

common in teenage boys, often with preexisting traction osteochondritis (Osgood-Schlatter) of the tibial tuberosity. Radiographically, avulsion fractures of the tibial tubercle may demonstrate discontinuity of the tuberosity tip, physeal widening, or intra-articular fracture. Isolated foci of mineralization adjacent to the tubercle are common normal variants, and typically do not reflect either avulsion fracture or Osgood-Schlatter.[45]

Patellar sleeve fractures also stem from contraction of the quadriceps, but typically during flexion.[45] In this fracture the intact patellar tendon avulses the cartilaginous inferior pole of the patella, potentially with a small bone fragment.[46] Patella alta and a joint effusion may be present. Because the insult of patellar sleeve fractures is primarily cartilaginous, plain film radiography tends to underestimate the extent of injury.

Tibial spine fractures result from forced hyperextension of the knee with avulsion at the insertion of the anterior cruciate ligament.[47] These fractures are difficult to detect on the AP view because of superimposition of bone, and are best seen on the tunnel or oblique views.[43] In the acute phase the superior border of the fragment is sharp and well corticated at the ligamentous attachment, whereas the inferior border lacks cortication (**Fig. 19**). These injuries are considered "anterior cruciate ligament equivalents," with operative management depending on the degree of displacement and size of the fragment.

Tibia

Classic toddler's fractures are common spiral fractures of the tibial diaphysis that often extend into the distal metaphysis. They result from torsional forces during early walking, but often present with pain referable to the ankle. These hairline fractures are usually nondisplaced and subtle cases are notoriously difficult to detect (**Fig. 20**).[21] Furthermore, in children who cannot bear weight, lower extremity fracture is often present even

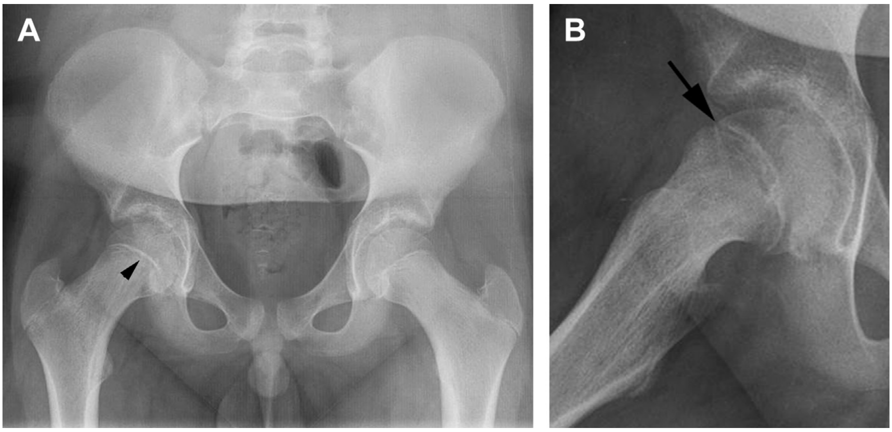

Fig. 18. (*A*) A 13-year-old boy with right slipped capital femoral epiphysis. AP radiograph of the pelvis demonstrates widening and irregularity of the proximal right femoral physis (*arrowhead*). (*B*) A 13-year-old boy with right slipped capital femoral epiphysis. Frog leg lateral radiograph of the right hip demonstrates mild posteromedial displacement of the femoral head with respect to the neck (*arrow*).

Fig. 19. AP radiograph in a 13-year-old boy after left knee injury demonstrates a minimally displaced tibial spine fracture (*arrows*). Incidental note is also made of a Segond fracture.

Fig. 20. Lateral radiograph of the tibia in an 18-month-old boy with limp demonstrates subtle nondisplaced toddler's fracture of the tibia (*arrow*).

with "normal" radiographs.[48] Given the insensitivity of plain film radiography for this common injury, follow-up radiographs in 10 to 14 days (vs MR imaging) may be beneficial if the clinical suspicion is high.

Variant (type II) toddler's fractures have been recently described by Swischuk and colleagues.[49] These are also seen during early ambulation, and result from impaction and hyperextension forces at the level of the developing tibial tuberosity. Radiographically, they present with anterior or lateral buckling, transverse hairline fracture, and increasing concavity of the tuberosity (**Fig. 21**). The tibial plateau may be tilted anteriorly and inferiorly.[21]

Trampoline fractures are similar injuries of the tibial metaphysis, although they occur in older children (2–5 years). These fractures result when a trampoline is shared between partners of unequal weight. The mat recoils upward, meeting the descending child and loading the tibia with impaction and hyperextension forces.[50] The tibial metaphysis fractures transversely and the plateau tilts anteriorly and inferiorly. Like toddler's fractures, these injuries are often subtle or occult (75%) on plain film radiography.[51]

Foot and Ankle

The cuboid toddler's fracture is a frequently missed fracture[52,53] that results from vertical loading of a hyperflexed forefoot, often during a fall from a bunk bed. The cuboid is impacted between the calcaneus and lateral metatarsals.[54] Acutely, radiographs demonstrate bandlike density of the cuboid because of superimposition of the trabecula, possibly with cortical deformation (**Fig. 22**). In the subacute and chronic phase, sclerosis predominates. Because there is substantial variation in the normal contour of the cuboid, comparison views may be helpful.

Metatarsal bunk bed fractures also involve an axial load, typically affecting the first metatarsal.[55] The typical radiographic appearance is of a buckle fracture with angulation (but no outward convexity) of the cortex (**Fig. 23**).

SUMMARY

Pediatric musculoskeletal trauma is easily missed on plain film radiography. Compared with the adult skeleton, immature bone is more porous and flexible, and the developing physes and apophyses are particularly prone to injury. Knowledge of

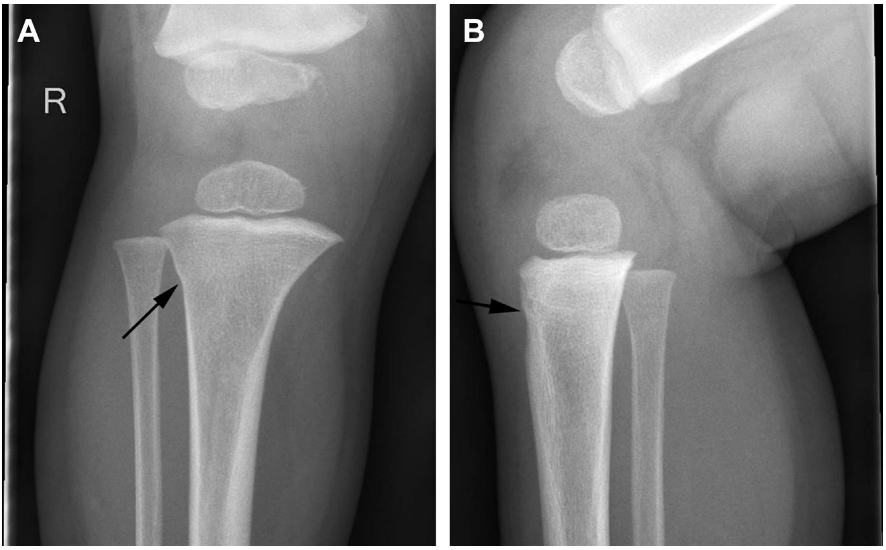

Fig. 21. (*A*) AP radiograph of the right knee in a 24 month old with limp demonstrates a subtle buckle fracture (*arrow*) at the proximal tibia near the tibial tubercle. (*B*) Lateral radiograph of the right knee in a 24 month old with limp demonstrates a subtle buckle fracture (*arrow*) at the proximal tibial tubercle.

unique fracture types and site-specific injury patterns is crucial to detecting subtle injury, and correct and early diagnosis can have a significant cosmetic and functional impact. Given the high degree of normal variation in the developing skeleton, comparison views of the (asymptomatic) contralateral limb, and/or short-term radiographic follow-up are reasonable strategies for managing equivocal cases. MR imaging may be considered in children who do not require sedation, if a confirmed diagnosis would lead to a change in management. Prompt diagnosis and management

Fig. 22. Oblique radiograph of the foot in a 16-month-old boy with limp demonstrates sclerosis within the proximal cuboid (*arrow*) in keeping with a healing toddler's fracture.

Fig. 23. AP radiograph of the foot in a 7-year-old boy with pain demonstrates a "bunk bed" fracture at the base of the first metatarsal (*arrow*).

has important implications for fracture healing, symptom relief, return to play/normal activities, and avoiding potential deformity. Understanding the classic imaging findings in subtle, common pediatric fractures helps ensure that these injuries are not missed.

REFERENCES

1. Heinrich SD, Gallagher D, Harris M, et al. Undiagnosed fractures in severely injury children and young adults. J Bone Joint Surg Am 1994;76-A: 561–72.
2. Segal LS, Shrader MW. Missed fractures in paediatric trauma patients. Acta Orthop Belg 2013;79: 608–15.
3. Berlin L. Malpractice and radiologists: an 11.5 year perspective. AJR Am J Roentgenol 1986;147:1291–8.
4. Little JT, Klionsky NB, Chaturvedi A, et al. Pediatric distal forearm and wrist injury: an imaging review. Radiographics 2013;34(2):472–90.
5. Frost HM, Schonau E. The “muscle-bone unit” in children and adolescents: a 2000 overview. J Pediatr Endocrinol Metab 2000;13(6):571–90.
6. Wattenbarger JM, Gruber HE, Phieffer LS. Physeal fractures: part I: histologic features of bone, cartilage, and bar formation in a small animal model. J Pediatr Orthop 2002;22(6):703–9.
7. Rathjen KE, Birch JG. Physeal injuries and growth disturbances. In: Beaty JH, Kasser JR, editors. Rockwood and Wilkins' fractures in children. 7th edition. Philadelphia: Lippincott Williams & Wilkins; 2010. p. 91–119.
8. Dwek JR. The periosteum: what is it, where is it, and what mimics it in its absence? Skeletal Radiol 2010; 39(4):319–23.
9. Jaimes C, Jimenez M, Shabshin N, et al. Taking the stress out of evaluating stress injuries in children. Radiographics 2012;32:537–55.
10. Soundappan SV, Holland AJ, Cass DT. Role of an extended tertiary survey in detecting missed injuries in children. J Trauma 2004;57:114–8.
11. Brooks A, Holroyd B, Riley B. Missed injury in major trauma patients. Injury 2004;35:407–10.
12. Enderson BL, Reath DB, Meadors J, et al. The tertiary trauma survey: a prospective study of missed injury. J Trauma 1990;30:666–9.
13. Sobus KM, Alexander MA, Harcke HT. Undetected musculoskeletal trauma in children with traumatic brain injury or spinal cord injury. Arch Phys Med Rehabil 1993;74:902–4.
14. Davis IC. Location of commonly missed fractures in a level 1 trauma center. RSNA 2012 conference paper.
15. Mounts J, Clingenpeel J, McGuire E, et al. Most frequently missed fractures in the emergency department. Clin Pediatr (Phila) 2011;50(3):183–6.
16. Slongo TF, Audigé L, AO Pediatric Classification Group. Fracture and dislocation classification compendium for children: the AO pediatric comprehensive classification of long bone fractures (PCCF). J Orthop Trauma 2007;21(suppl 10):S135–60.
17. Hernandez JA, Swischuk LE, Yngve DA, et al. The angled buckle fracture in pediatrics: a frequently missed fracture. Emerg Radiol 1996;(10):71–2.
18. Bae DS, Howard AW. Distal radius fractures: what is the evidence? J Pediatr Orthop 2012;32(suppl 2): S128–30.
19. Malik M, Demos TC, Lomansney LM, et al. Bowing fracture with literature review. Orthopedics 2016; 39(1):e204–8.
20. Siwschuk LE. Emergency imaging of the acutely ill or injured child. 4th edition. Lippincott Williams & Wilkings. p. 306–10.
21. Swischuk LE, Hernandez JA. Frequently missed fractures in children (value of comparative views). Emerg Radiol 2004;11:22–8.
22. Vorlat P, De Boeck H. Bowing fractures of the forearm in children: a long-term followup. Clin Orthop Relat Res 2003;413(413):233–7.
23. Randsorg PH, Siversten EA. Classification of distal radius fractures in children: good inter- and intraobserver reliability, which improves with clinical experience. BMC Musculoskelet Disord 2012;13:6.
24. Rogers LF, Poznanski AK. Imaging of epiphyseal injuries. Radiology 1994;191(2):297–308.
25. Cope R. Radiologic history exhibit. Charles Thurstan Holland, 1863-1941. Radiographics 1995;15(2):481–8.
26. Jadhav SP, Swischuk LE. Commonly missed subtle skeletal abnormalities in children: a pictorial review. Emerg Radiol 2008;15:291–8.
27. May MM, Bishop JY. Shoulder injuries in young athletes. Pediatr Radiol 2013;43(suppl 1):S135–40.
28. DiPaola M, Marchetto P. Coracoid process fracture with acromioclavicular joint separation in an American football player: a case report and literature review. Am J Orthop 2009;38:37–9 [discussion: 40].
29. Davis KW. Imaging pediatric sports injuries: upper extremity. Radiol Clin North Am 2010;48(6):1199–211.
30. Delgado J, Jaramillo D, Chauvin NA. Imaging of the injured pediatric athlete: upper extremity. Radiographics 2016;26:1672–2678.
31. Carson WG Jr, Gasser SI. Little leaguer's shoulder: a report of 23 cases. Am J Sports Med 1998;26(4): 575–80.
32. McCulloch P, Henley BM, Linnau KF. Radiographic clues for high-energy trauma: three cases of sterno clavicular dislocation. AJR Am J Roentgenol 2001; 176:1534.
33. Dwek JR, Chung CB. A systematic method for evaluation of pediatric sports injuries of the elbow. Pediatr Radiol 2013;43(suppl 1):S120–8.
34. Rogers LF, Mabave S Jr, White H, et al. Plastic bowing, torus, and greenstick supracondylar fractures of the

humerus: radiographic clues to obscure fractures of the elbow in children. Radiology 1978;128:145–50.
35. Greenspan A. Orthopedic imaging, a practical approach. Lippincott Williams & Wilkins; 2004. ISBN:0781750067.
36. John SD, Wherry K, Swischuk LE, et al. Improving detection of pediatric elbow fractures by understanding their mechanics. Radiographics 1996; 16(6):1443–60.
37. Emery KH, Zingula SN, Anton CG, et al. Pediatric elbow fractures: a new angle on an old topic. Pediatr Radiol 2016;46(1):61–6.
38. Crawford AH. Current concepts review: slipped capital femoral epiphysis. J Bone Joint Surg Am 1988; 70:1422–7.
39. Boles CA, El-khoury GY. Slipped capital femoral epiphysis. Radiographics 1997;17(4):809–23.
40. Hesper T, Zilkens C, Bittersohl B, et al. Imaging modalities in patients with slipped capital femoral epiphysis. J Child Orthop 2017;11:99–106.
41. Green DW, Mogekwu N, Scher DM, et al. A modification of Klein's line to improve sensitivity of the anterior-posterior radiograph in slipped capital femoral epiphysis. J Pediatr Orthop 2009;29(5):449–53.
42. Sanders TG, Zlatkin MB. Avulsion injuries of the pelvis. Semin Musculoskelet Radiol 2008;12(1):42–53.
43. Stevens MA, El-Khoury GY, Kathol MH, et al. Imaging features of avulsion injuries. Radiographics 1999;19:655–72.
44. Brandser EA, El-Koury GY, Kathol MH. Adolescent hamstring avulsions that simulate tumors. Emerg Radiol 1995;2:273–8.
45. Dupuis CS, Westra SJ, Makris J, et al. Injuries and conditions of the extensor mechanism of the pediatric knee. Radiographics 2009;29:877–86.
46. Green NE, Swiontkowski MF, editors. Skeletal trauma in children. 3rd edition. Philadelphia: Saunders; 2002.
47. Gottsegen CJ, Eyer BA, White EA, et al. Avulsion fractures of the knee: imaging findings and clinical significance. Radiographics 2008;28(6):1755–70.
48. Naranja RJ, Gregg JR, Dormans JP, et al. Pediatric Fracture without radiographic abnormality. Clin Orthop Relat Res 1997;342:141–6.
49. Swischuk LE, John SD, Tschoepe EJ. Upper tibial hyperextension fractures in infants: another occult toddler's fracture. Pediatr Radiol 1999;29:6–9.
50. Boyer RS, Jaffe RB, Nixon GW, et al. Trampoline fracture of the proximal tibia in children. AJR Am J Roentgenol 1986;146(1):83–5.
51. Hauth E, Jaeger H, Luckey P, et al. MR imaging for detecting trampoline fractures in children. BMC Pediatr 2017;17:27.
52. Simonian PT, Vaheyj W, Rosenbaum DM, et al. Fracture of the cuboid in children: a source of leg symptoms. J Bone Joint Surg Am 1995;77:104–6.
53. Englaro EE, Gelfand MJ, Paltiel HJ. Bone scintigraphy in preschool children with lower extremity pain of unknown origin. J Nucl Med 1992;33:351–4.
54. John SD, Moorthy CS, Swischuk LE. Expanding the concept of the toddler's fracture. Radiographics 1997;17:367–76.
55. Johnson GF. Pediatric Lisfranc injury: ''bunk-bed'' fracture. AJR Am J Roentgenol 1981;137:1041–4.