The Emergency Evaluation and Management of Pediatric Extremity Fractures

Kathy Boutis, MD, MSc, FRCPC

KEYWORDS

• Children • Fractures • Diagnosis • Management • Emergency

KEY POINTS

- There are validated clinical decision rules that aim to reduce unnecessary radiographs in children who present with wrist, knee, and ankle injuries.
- Abuse should be considered in any infant who is not walking and presents with a fracture.
- A conservative approach is encouraged that includes immobilization and referral to an orthopedic surgeon (emergency or outpatient depending on the severity of the fracture) if there is radiographic evidence of a fracture or a high clinical suspicion of a fracture without radiographic evidence with the following exceptions: low-risk distal fibular ankle and distal radius buckle fractures; the latter minor fractures can be managed with a removable device, return to activities as guided by the patient's symptoms, and follow-up with a primary care provider.
- Approximately 10% of pediatric fractures are not identified on the initial emergency department visit, and this is particularly true when the emergency department physician has a low suspicion for a fracture or the location of the injury is a joint. Although most missed fractures are minor, the most commonly missed serious fractures are the Tillaux fracture and the Monteggia fracture.

ANATOMIC AND HEALING PRINCIPLES

The anatomy of the pediatric musculoskeletal system changes with the growth and development that occurs in children. The long bones of children consist of discrete anatomic areas. The physis is an area of growth cartilage and may occur at one or both ends of a long bone. The area of bone between the physis and the

Disclosure Statement: Dr K. Boutis is the academic director of ImageSim Continued Professional Development and Training platform (www.imagesim.com). ImageSim operates as nonprofit course under the academic umbrellas of the Hospital for Sick Children and the University of Toronto. Dr K. Boutis does not receive any funds for her participation the management of ImageSim.
Division of Emergency Medicine, ImageSim, Research Institute, The Hospital for Sick Children, University of Toronto, 555 University Avenue, Toronto, Ontario M5G1X8, Canada
E-mail address: Kathy.boutis@sickkids.ca

Emerg Med Clin N Am 38 (2020) 31–59
https://doi.org/10.1016/j.emc.2019.09.003 emed.theclinics.com
0733-8627/20/

adjacent joint is the *epiphysis*. The midshaft of a long bone is the *diaphysis*. The *metaphysis* of a long bone is the area between the diaphysis and the physis (**Fig. 1**).

Children's bones, especially in younger children, are softer and more pliable than those of adults, and therefore can respond to mechanical stress by bowing and buckling rather than routinely fracturing through and through like adult bone fractures. The periosteum of the diaphysis and the metaphysis is thick in children, and is continuous from the metaphysis to the epiphysis, surrounding and protecting the mechanically weaker physis. The physis is sensitive to alterations in the blood supply, and physeal injuries can result in a bony bridge resulting in growth arrest.[1] On the other hand, the ligaments of children are stronger and more compliant than in adults, and ligaments tolerate mechanical forces better than the weaker physis.

The pediatric musculoskeletal system also has some distinctive healing features. Remodeling allows for a certain degree of angulation in pediatric fractures, as children can remodel with bone growth to nearly perfect anatomic alignment without any intervention except for immobilization. The degree of remodeling is greatest in young children, if there is a metaphyseal fracture, or if the deformity occurs in the plane of motion of the adjacent joint.[2] Therefore, the acceptable amount of angulation, minimizing the need for reduction, in pediatric fractures is much greater than that in similar adult fractures. In addition, there is often sufficient callus formation such that nonunion almost never occurs in displaced fractures.[3] Therefore, even though fractures occur more frequently in children than they do in adults, they have an exceptional healing capacity and usually have good outcomes.

Fig. 1. Anatomy of a pediatric bone. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

FRACTURE PATTERNS

Physeal Fractures

The Salter and Harris classification system classifies physeal fractures with respect to prognosis for growth disturbance. It is important to note that the risk of growth arrest varies with the particular bone as well. That is, the risk for growth arrest in a Type II fracture of the distal fibula is not the same as this risk in Type II fractures of the distal tibia. Differential risks largely relates to the anatomy of the growth plate and its vascular supply. In general, the more linear the growth plate (eg, distal fibula) the less risk for vascular disturbance in the event of a growth plate fracture.[1]

Salter-Harris Type I fractures occur when there is cleavage through the hypertrophic cell zone of the physis, with the reproductive cells of the physis remaining with the epiphysis. There is often separation from the metaphysis, which is often temporary or can result in a displaced epiphysis; however, there are no associated fragments of bone. In the absence of epiphyseal displacement, radiographs only demonstrate soft tissue swelling. The diagnosis is clinical with tenderness and swelling maximal over the physis. Type I injuries have a very low incidence of growth disturbances.

Salter-Harris Type II fractures occur when the fracture line extends along the physis and then out through a part of the metaphyseal bone. Growth is often preserved because the reproductive layers of the physis maintain their position with the epiphysis and the epiphyseal circulation. Diagnosis is made radiographically by noting a triangular-shaped metaphyseal fragment (ie, Thurstan Holland fragment) (**Fig. 2**).

Fig. 2. Salter-Harris II of the distal radius. Arrow points to the fracture in the metaphysis that extends into the growth plate. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Salter-Harris Type III fractures have a fracture line that extends into the intra-articular area from the epiphysis, through the physis, with the cleavage plane continuing to the periphery. The prognosis for subsequent bone growth relates to the preservation of circulation to the epiphyseal bone fragment; however, the prognosis is usually quite favorable. The diagnosis of a Type III injury is made radiographically (**Fig. 3**). Occasionally, additional imaging with computed tomography (CT) or magnetic resonance imaging (MRI) is used to better evaluate the extent of the fracture and articular surface involvement.

Salter-Harris Type IV fractures have a fracture line that originates at the articular surface and extends through the epiphysis, the entire thickness of the physis, and continues through the metaphysis. The diagnosis of a Type IV injury is made radiographically on identification of epiphyseal and metaphyseal fragments (**Fig. 4**). The risk of growth disturbance with this type of fracture can be significant.

Salter-Harris Type V fractures are rare and typically are the result of a profound compressive force transmitted to the physis. The diagnosis of a Type V injury may be difficult initially, leading to a lack of appreciation of the severity of the injury. The mechanism of injury should point to a Type V injury, as these injuries are typically associated with fall from a great height. Radiographs may appear normal or may demonstrate focal narrowing of the physeal plate and obtaining comparison views of the uninjured side may be beneficial.

Torus and Greenstick Fractures

Compressive forces may result in a bulging or buckling of the periosteum termed a *torus* or *buckle* fracture. Any asymmetry, bulging, or deviation of the cortical margin indicates a torus fracture (**Fig. 5**), although it may be subtle.

A *greenstick* fracture is characterized by cortical disruption on the convex side of the bone, with a buckling or intact cortex on the concave side of the bone. These injuries typically occur at the metaphyseal-diaphyseal junction of a long bone (**Fig. 6**).

Fig. 3. Salter-Harris III of the distal tibia. Arrow points to the fracture in the epiphysis that extends into the joint. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Fig. 4. Salter-Harris IV of the distal tibia. Arrows highlight the fracture in the metaphysis and epiphysis with extension into the joint. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

PLASTIC DEFORMITIES

Plastic deformities are also referred to as *bowing* fractures and typically occur after a fall on the outstretched hand (FOOSH). The classic clinical hallmark is pain out of proportion to the physical examination findings. In forearm bowing fractures, pain is maximal on protonation/supination. The cortex of the diaphysis of the long bone is deformed, but the periosteum along the entire diaphysis is preserved. Moderate-severe plastic deformity is usually obvious clinically. However, in mild cases of bowing injuries, comparison films of the uninvolved extremity can be helpful (Fig. 7) to ensure that these injuries are not missed.

UPPER EXTREMITY INJURIES

Clavicle

Clavicle fractures occur during infancy as a result of birth trauma or during childhood as a result of FOOSH or onto the lateral side of the shoulder. Mid-clavicular fractures are the most common, whereas medial and lateral clavicular fractures are relatively rare.

Middle third of clavicle

Most of these injuries can be treated with analgesics, support of the injury with a broad arm sling for 3 to 4 weeks, and follow-up with the primary care physician (PCP).[4]

Fig. 5. Buckle fracture of the distal radius. Arrow identifies the buckling in the cortex. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

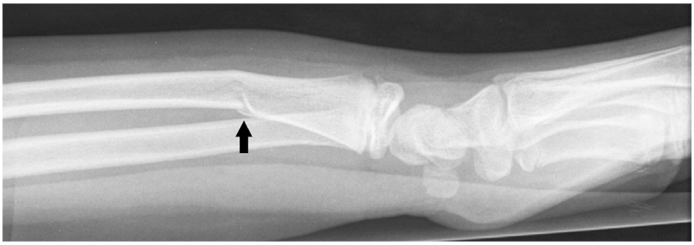

Fig. 6. Greenstick fracture of the distal radius. Arrow identifies the cortical break in the meta-diaphyseal junction. There is also buckling on the opposite of the cortex. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Fig. 7. (*A*) Bowing of the radius and ulna of the injured right arm. (*B*) A normal radius and ulna on the uninjured left arm. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Urgent orthopedic consultation is indicated when a child is >12 years, the fracture is ≥100% displaced or shortened ≥2 cm, there is skin tenting, neurovascular compromise, or fracture through a pathologic lesion.[5]

Medial clavicle

Given the strong ligamentous attachment of the clavicle to the sternum, injuries to this area are usually epiphyseal disruptions. Urgent orthopedic consultation is recommended for these injuries.

Lateral clavicle

Minimally displaced distal clavicle fractures only need immobilization with a sling or equivalent. Urgent orthopedic consultation is needed for fractures with 100% displacement, ≥2 cm shortening or associated acromioclavicular dislocation.[6]

Humerus

Midshaft humeral fractures typically occur from a FOOSH or a direct blow to the upper arm.

Proximal humerus

These fractures may occur at the physis or the proximal humeral metaphysis, and they have an extraordinary ability to repair themselves. Proximal humeral physeal fractures occur more commonly in adolescence because this area becomes relatively weak during this time of rapid growth. Fractures of the proximal humeral metaphysis are more common in preadolescents. Treatment depends on the age of the child and degree of displacement or angulation. In general, children $\leq$10 to 12 years with a proximal humeral fracture that is displaced $\leq$50% and less than 60° angulated can be treated in a broad arm sling for 4 weeks and follow-up in an orthopedics clinic within a week.[7,8] If the child is >10 to 12 years with greater than 50% displacement or greater than 30° angulation, there is a pathologic fracture, or neurovascular compromise then urgent referral to an orthopedic surgeon is indicated.[9,10]

Humeral diaphysis

Direct trauma to the humerus can cause a transverse fracture, and a violent rotation can cause a spiral fracture. Spiral/oblique fractures of the humeral diaphysis in infants and toddlers have been strongly linked to child abuse.[11,12] Rarely, the fracture fragment may injure the radial nerve as it runs in the radial groove. Thus, assess radial nerve function (eg, wrist extensors and supinators, sensation of dorsoradial hand, thumb, and second digits) on initial examination and following any splinting. The potential for healing is good, and treatment is usually immobilization in a long-arm plaster splint with orthopedic follow-up. Orthopedic consultation is recommended for midshaft humeral fractures that present with a clinical deformity or angulation more than 20° in children and 10° in adolescents.[10]

Elbow

Acute pediatric elbow injuries usually are related to falls. The large cartilaginous component of the elbow makes radiograph interpretation difficult.[13] As a result, compared with other fractures, elbow fractures in children are commonly missed in the emergency department (ED).[14] True lateral and anteroposterior radiographs of the elbow are essential to diagnose elbow fractures. Because competency in pediatric elbow interpretation is difficult to achieve, many clinicians obtain comparison radiographs of the uninjured side as a reference to what is normal.[15]

Supracondylar fractures

Most supracondylar fractures occur in children from 3 to 10 years with the peak incidence occurring between ages 5 and 7 years. The extension type supracondylar fracture is by far the most common, accounting for 90% to 98% of cases.

An extension-type supracondylar fracture is caused by a FOOSH with the elbow hyperextended. A flexion-type fracture results from falling on a flexed elbow and is rare. The complications of a supracondylar fracture, although uncommon, range from transient neurapraxia to Volkmann ischemic contracture, with the most common being an injury to the anterior interosseous nerve resulting in the "pointing finger sign."

Type I fractures are displaced $\leq$2 mm and may have a posterior fat pad sign as the only radiographic finding (Fig. 8). Type I supracondylar fractures are inherently stable. The goal of therapy is pain control and immobilization with a long-arm posterior splint with the elbow at 90° and the forearm in protonation or neutral rotation for 3 weeks. Arrange orthopedic follow-up within 2 to 7 days. Although collar and cuff

Fig. 8. Type I supracondylar fracture. Smaller arrow points to the posterior fat pad. Larger arrow points to the displaced distal humerus fracture. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

immobilization is used in some centers, it does not offer as good pain management as splinting.[16,17]

Type II fractures are angulated to varying degrees, but the posterior cortex of the humerus is intact (**Fig. 9**).

Type III fractures are completely displaced with no cortical contact (**Fig. 10**). The distal fragment may be posteromedially (Type IIIa) rotated and, as such, can impinge against the radial nerve or be posterolaterally (Type IIIb) rotated. In posterolaterally displaced fractures, the brachial artery and median nerve are at risk for injury, and compartment syndrome can develop.[18,19] Consult orthopedic surgery emergently (within 1 hour) if there is a suspicion of compartment syndrome, if there is loss of radial pulses, or a cool, white hand. Otherwise, Type II and III fractures need urgent orthopedic consultation (within 4 hours) in the ED for definitive management that typically includes operative pinning.[20]

Lateral condylar fractures

These fractures occur when there is varus stress on an extended elbow with the forearm in supination. Swelling and tenderness are usually limited to the lateral elbow, and neurovascular injury is uncommon. The diagnosis can be made with standard anteroposterior and lateral views, but obtain an oblique view if the clinical suspicion is high. In Type 1 lateral condylar fractures, defined by $\leq$2 mm displacement, the child's elbow injury can be treated in a long-arm backslab with the elbow flexed at 90° and broad arm sling (**Fig. 11**).[21,22] Type 2 lateral condylar fractures occur when there is >2 mm displacement with congruity of the articular surface, whereas Type 3 occur with greater than 2 mm displacement and without congruity of the articular surface. Type 2 and 3 lateral condylar fractures require urgent orthopedic consultation because these fractures often require open reduction and internal fixation (ORIF). Nonunion, malunion, osteonecrosis, cubitus valgus, and ulnar nerve palsy are well-described complications.[23]

Fig. 9. Type II supracondylar fracture. Larger arrow points to the posterior fat pad and smaller arrow points to the subtle lucency in the cortex. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Fig. 10. Type III supracondylar fracture. The area in the circle identifies a markedly displaced supracondylar fracture. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Fig. 11. Lateral condylar fracture of distal humerus. The arrow points to the fragment that represents a lateral condylar fracture. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Medial epicondyle fractures

These fractures tend to occur in older children, between the ages of 10 and 14 years. Simple fractures of the medial epicondyle are extra-articular injuries with limited soft tissue involvement, but nearly half of these injuries are associated with elbow dislocation; in such injuries, the epicondyle can become entrapped in the joint.[24,25] Fractures are classified by the amount of displacement and associated extremity injuries (**Fig. 12**). Typically, if there is <5 mm of displacement, these fractures can be managed in a long-arm backslab at 90° elbow flexion for 3 weeks and follow-up in orthopedics. More than 5 mm of displacement is an indication for urgent orthopedic consultation. It is important to distinguish between a medial epicondyle fracture from a medial condyle fracture. Medial condyle fractures are intra-articular and require urgent review by an orthopedic surgeon.

Fig. 12. Medial epicondylar fracture of the distal humerus. The arrow points to the fragment that represents a medial condylar fracture. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Monteggia fracture dislocation

This injury refers to the dislocation of the radial head (proximal radioulnar joint) with fracture of the ulna. This type of injury is the most commonly missed serious fracture of the elbow. A good general rule to avoid missing this injury is that if there is an ulnar fracture always look for an associated injury in the radius. The Bado classification system identifies 4 types of Monteggia fractures. The most common type occurs when there is an anterior dislocation of the radial head with fracture of the ulna shaft (Fig. 13). Emergent orthopedic consultation is indicated for this fracture as reduction is always required for these injuries.

Olecranon fractures

These injuries generally result from a fall on the elbow and are best seen on the lateral view. Orthopedic consultation is best to guide treatment. If the fracture is displaced ≤5 mm, it should be immobilized in the most stable position, usually 90° of elbow flexion, for 3 to 6 weeks.[26] ORIF is indicated for unstable fractures. Olecranon fractures occur in association with fractures of the radial head and neck. A "simple"

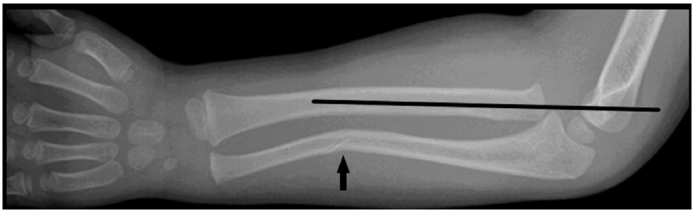

Fig. 13. Monteggia fracture. The transverse line demonstrates a radial head dislocation and the arrow points to the associated ulnar fracture. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

olecranon fracture may be part of a Monteggia lesion, so the radial head position should be carefully evaluated.

Radial head and neck fractures

The radial neck is fractured more frequently than the radial head, and most radial neck fractures occur through the metaphysis (**Fig. 14**). The most common mechanism is a FOOSH. Obtain orthopedic consultation to guide treatment. Reduction is often necessary when angulation is >35^0 or displacement is greater than 60%.[27]

Elbow dislocation

These are uncommon in children, but the most common type of dislocation is posterior and often there are associated fractures of the medial and lateral epicondyle or radial neck. Neurologic injury is associated with approximately 10% of elbow dislocations. Ulnar neuropathy is the most common and is usually associated with medial epicondyle entrapment. Median nerve injury may be caused by entrapment of the nerve inside the joint, behind the medial epicondyle, or in an epicondyle fracture. Radial nerve and arterial injury are both rare. Consult orthopedics emergently if a neurovascular injury is suspected. After reduction and review of postreduction radiographs, immobilize the reduced elbow in a posterior mold and refer for orthopedic follow-up within one week.

Subluxation of the radial head

This is otherwise known as a *pulled elbow* or *nursemaid's elbow.* It is a common injury in young children. It can occur any time from birth to 6 years of age but commonly occurs from 1 to 4 years of age. The mechanism of injury is often a sudden pull on the arm, usually by an adult or taller person. The force pulls the radius through the annular ligament, resulting in subluxation (partial dislocation) of the radial head. The child experiences sudden acute pain and loss of function of the affected arm. On examination, the child holds the involved arm in slight flexion and protonation, and there is no focal swelling or tenderness. However, there is significant pain with protonation/supination of the forearm. This is a clinical diagnosis and should not be confused with other radial head pathology (eg, radial head/neck fractures) or bowing fractures that can also illicit tenderness with protonation/supination. Distinguishing features in favor of a pulled elbow include lack of focal symptoms/signs, younger age, and relatively benign mechanisms. There are 2 favored techniques to reduce a pulled elbow.[28] The first is called the "supination-flexion" method. The provider grasps the humeral epicondyles with their thumb over the radial head, and with the other hand, quickly supinates the forearm and flexes the elbow. An alternative method is called "hyperpronation." Hold the child's hand as if shaking hands, hold the epicondyles with your other hand, extend the forearm, and pronate quickly. If one method is not successful, you can try the alternative method. A recent meta-analysis concluded that hyperpronation was more

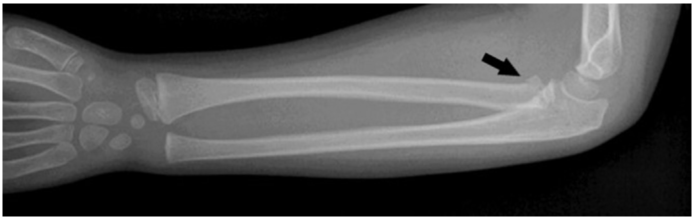

Fig. 14. Radial neck fracture. The arrow points to the lucency located at the radial neck. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

effective in terms of success rate and less painful compared with the supination-flexion maneuver.[29] If successful, the pain resolves after reduction and normal arm movement is quickly regained.

Forearm

Childhood forearm fractures are the most common pediatric fractures,[30] and most often occur after a FOOSH. In general, with the presence of any localized pain, swelling, or limited movement, a radiograph of the affected area is recommended. The Amsterdam Pediatric Wrist rules have been validated in children 3 to 18 years and based on historical and physical examination variables provides a probability for the presence of a fracture and the recommendation to obtain or not to obtain radiographs. These rules have the potential to reduce unnecessary wrist radiographs in children by approximately 20%, with a reported sensitivity of 98%.[31]

Radius and ulna diaphyseal fractures

Injuries of the shaft can remain unstable despite attempts at closed reduction and occasionally require open fixation. Proximal third shaft fractures are relatively uncommon. In skeletally immature children younger than 10 years, angulation less than 10° often does not require anatomic reduction.[32]

Bowing deformities

These injuries can be difficult to diagnose and often missed. Radiologic comparison with the uninjured side may be necessary in mild cases (see Fig. 7). Failure to correct bowing (which tends to be along the whole bone) may lead to permanent deformity and disability. Although minimally angulated bowing fractures and those in younger children can often be managed in a splint/cast and follow-up with an orthopedic surgeon, more advanced bowing fractures may require completion of the break to establish proper realignment. Urgent orthopedic consultation is required for any plastic deformities. In general, proper reduction and realignment is recommended for any angulation $\geq$20° in children younger than 10 years or $\geq$15° degrees in children older than 10 years.[33]

Isolated ulnar fractures

These are rare and caused by a direct blow. Typically, those that are minimally angulated can be managed with a splint and follow-up in an orthopedic clinic. If caused by an indirect force, typically, there is an associated fracture or dislocation of the radius. As described previously, the combination of an ulnar fracture with a dislocation of the radial head is called *Monteggia fracture* (see Fig. 13). *Galeazzi fracture* is a radial shaft fracture with an associated dislocation of the distal radioulnar joint. Although this injury is uncommon, immediate orthopedic consultation is warranted.

Radius/ulna metaphyseal greenstick or complete fractures

Younger children and more distal injuries have a greater capacity for remodeling. In general, in girls younger than 10 years and boys younger than 12 years with fractures that are $\leq$15° angulated in the sagittal and $\leq$5 mm displaced in the frontal plane do not need reduction and can be managed in a short arm circumferential cast or splint for 4 weeks to 6 weeks.[33,34] Follow-up with an orthopedic surgeon is still recommended because these fractures can be unstable and can displace further in follow-up regardless of if they are managed in a cast or a splint.[35] For greater degrees of angulation, consult orthopedic surgery to determine the need for urgent reduction.

Radius and ulnar metaphyseal torus fractures

Torus or buckle-type fractures (see Fig. 5) of the distal forearm are the most common pediatric fracture. There is point tenderness over the distal radius or ulna, occasionally with associated localized swelling. Distal radius buckle fractures can be radiologically subtle and therefore can be missed without careful review of both the anteroposterior and lateral radiograph views. In contrast, approximately 10% of cases thought to have a distal radius buckle fracture actually have a more advanced or unstable fracture (eg, distal radius greenstick fracture, distal radius Salter-Harris II fracture).[36] Because errors are likely to occur routinely in these and other pediatric fractures, it is important that EDs have a robust quality assurance program to correct radiograph interpretation errors so that appropriate management can be applied. Correctly diagnosed distal radius buckle fractures are best treated by splinting in a position of function with the PCP within 1 to 3 weeksfunction with follow up at the PCP office within 1 to 3 weeks of the initial injury.[37,38] Three studies have recommended home removal of the splint as safe and cost-effective.[39–41] Regardless, orthopedic surgery referral should does not need to be routine; rather, orthopedic referral should be reserved for cases that are not healing as expected.

Distal radius physical fractures

Salter-Harris I fractures of the distal radial physis are assumed if there is point tenderness or swelling over the distal radius physis and no radiographic evidence of a visible bony fracture. These injuries are rarely associated with growth disturbances. Undisplaced or minimally displaced Salter-Harris I fractures should be immobilized with a below-elbow splint and followed in an orthopedic clinic within 1 week. Significantly displaced Salter-Harris I often require urgent closed reduction in the ED. Consult orthopedic surgery for guidance on when reduction is recommended. Salter-Harris Type II injuries (see **Fig. 2**) can be managed as per Salter-Harris I fractures of the distal radius.[3] For Salter-Harris Type III, IV, and V injuries, urgent orthopedic consultation is necessary.

Carpal bone injuries

Fractures of the carpal bones are quite rare in the skeletally immature child. However, these injuries increase in frequency in the skeletally mature adolescent population. Most are sports-related injuries. Fracture patterns and presentation are similar to the adult, and scaphoid fractures are the most common type, although still relatively rare.[42] However, unlike adults, nonunion is less common in children.[43] Immobilize any suspected fracture of a carpal bone in a thumb spica splint and arrange early orthopedic follow-up, even in the absence of radiographic findings. Repeat plain radiographs, CT, or MRI may be needed at follow-up for further assessment of the injury.

Phalangeal fractures

The most common injury is to the distal phalanx resulting from a crush injury, often when a door has been closed on a child's finger. If there is an associated nail bed injury, the nail bed may need to be repaired, and the fracture is considered "open." The use of prophylactic antibiotics in "open" fractures of the distal tuft remains controversial, with no clear evidence of benefit.[44] Consultation with an orthopedic or plastic surgeon may be appropriate for repair of the nail bed if needed. Immobilize a distal phalanx "tuft" fracture with a finger splint. Phalangeal shaft fractures should be assessed for displacement, rotational deformity, and tendon disruption. Significantly displaced, rotated fractures or those with tendon disruption need orthopedic/plastic surgery consultation for reduction and repair.

LOWER EXTREMITY INJURIES

Pelvis

The immature, relatively cartilaginous pediatric pelvis is somewhat pliable. There are 2 broad categories of pelvic fractures, nonavulsive and avulsive. Nonavulsive pediatric pelvic fractures usually result from significant force, and the most common mechanism is pedestrian versus motor vehicle collisions.[45] A child with a pelvic fracture should be assumed to have multisystem trauma and be transferred to a level 1 pediatric trauma center. Avulsion-type injuries of the pelvis are usually seen in the adolescent and are unusual before 8 years of age (**Fig. 15**). These typically result from sudden contraction of musculature attached to the pelvis and occur during athletic activities. The child will often complain of sudden pain and have point tenderness over the fracture site. Nearly all avulsion fractures can be managed conservatively with rest, limitation of activity until symptoms resolve, and orthopedic follow-up.

Femur

Trauma can result in an epiphyseal disruption or a fracture of the head, neck, trochanteric, or subtrochanteric region of the femur. Proximal fractures involving the femoral head or neck have a high risk of complications (eg, avascular necrosis, growth arrest). Treatment is almost always urgent operative repair. Traumatic dislocations of the hip are rare in the pediatric population and tend to occur only in older children/adolescents. Hip dislocations are most often posterior and result from a significant trauma. Treatment for pediatric hip dislocations is urgent closed reduction. Immediate orthopedic consultation is indicated, as any significant delay in reduction is associated with a higher incidence of complications including sciatic nerve injury.

Femoral shaft

The most common mechanisms of injury are falls, pedestrian versus automobile incidents, motor vehicle collisions, and sports-related injuries. Although significant force is usually required to fracture the femoral shaft, in young healthy ambulatory children from 1 to 4 years, femur fractures can occur with low-velocity injuries such as a short fall or twisting/stumbling injury.[46] Nevertheless, it is important to consider child abuse in a child with a femur fracture who is not yet walking.[47]

The clinical findings of a femur fracture are usually obvious. There is typically tenderness and swelling over the fracture site. The child may hold the leg externally rotated and will likely refuse to bear weight. The leg may be shortened. Given the high degree of force typically needed to fracture the femur, perform a thorough evaluation for multisystem trauma. Hypotension is usually not related to an isolated femur fracture in a young child and practitioners are encouraged to look for other injuries.[47] All femoral shaft fractures require immediate orthopedic consultation.[48]

Fig. 15. Pelvic avulsion fracture. The arrow points to the avulsion fracture located at the anterior inferior iliac spine. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Slipped capital femoral epiphysis

This is characterized by slipping of the femoral epiphysis of the hip and is the most common cause of hip disability in adolescents. The etiology is multifactorial, and any child may develop slipped capital femoral epiphysis (SCFE) during a growth spurt; however, most affected children are obese adolescents whose hips are exposed to repetitive minimal trauma. Boys with SCFE present at an average age of 14 to 16 years. Girls typically present earlier, at approximately 11 to 13 years. The slippage may be chronic, acute, or acute-on-chronic. Acute SCFE are rare but quite dramatic. The child cannot bear weight, and surgery for reduction and fixation is done on an urgent basis. Acute worsening of mild chronic displacement may occur after minimal or no trauma. In cases of chronic slip, clinically, the child may develop hip (groin) pain, or pain is referred to the thigh or, much more commonly, the knee. The pain may be vague and chronic in nature. Obtain bilateral hip radiographs in any adolescent with chronic pain in the groin, hip, thigh, or knee to evaluate for SCFE because delay in diagnosis can lead to significant disability. Adequate radiographs include both anteroposterior and lateral hip views (ie, Lowenstein view). Both hips should be imaged given the high incidence of bilateral disease. The use of frog leg views is controversial given the potential for further epiphyseal displacement in this position. Radiographically, epiphyseal slippage may be detected by examining the anatomic relationship of the femoral neck to the femoral head (**Fig. 16**).

Obtain orthopedic consultation for any child with pain suspicious for SCFE in the ED. Once the diagnosis is made, the goal of treatment is to prevent further slippage: management includes strict non–weight-bearing and definitive operative management. Complications include avascular necrosis of the hip and premature closure of the physis.

Knee

Evaluation typically includes 2 radiographic views (anteroposterior and lateral) of the knee. The Ottawa Knee Rules have been validated for children older than 5 years and can help determine the need for radiographs.[49]

Fractures through the distal femoral physis

These injuries are uncommon but are at high risk of developing significant complications. The popliteal artery lies close to the distal femoral metaphysis and may be

Fig. 16. Slipped Capital Femoral Epiphysis. The arrow points to the slipped epiphysis on the femoral head. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

injured along with the peroneal nerve. Growth arrest may also occur secondary to permanent physeal damage. Although Salter-Harris Type I injuries may not be appreciated on plain radiographs, any child suspected of having a significant injury should receive orthopedic follow-up. Any displaced distal femoral physeal disruption needs immediate orthopedic evaluation for reduction.

Patellar dislocations

The typical mechanism of this injury is one of pivoting the knee on a fixed lower leg. There is often a history of the "knee popping out of place." If the patient remains dislocated in the ED, the displaced patella usually sits laterally, and the knee is held in flexion. Reduction need not be delayed for radiographs and is easily accomplished by gently extending the knee while another provider helps "lift" the patella into place. Obtain radiographs after the reduction to assess for fractures, which are most typically seen at either the lateral femoral condyle or the medial margin of the patella. Place the child in a knee immobilizer and arrange follow-up with orthopedics within 1 to 2 weeks.

Patellar fractures

These fractures are uncommon in children and usually occur from a direct blunt force. The "sleeve" fracture of the patella, in which the distal patellar "sleeve" is avulsed from the body of the patella, is a patellar fracture unique to children. The typical mechanism of an avulsion "sleeve" fracture is a forceful contraction of the quadriceps against a fixed lower leg. Consultation with an orthopedist is advised to determine the appropriate treatment.

Fractures of the tibial spine

From a mechanical viewpoint, an avulsion fracture of the tibial spine is the equivalent of an anterior cruciate ligament rupture in an adult. The anterior cruciate ligament inserts on the tibial eminence, also known as the anterior tibial spine, and this ligament and its insertion are much stronger than the epiphyseal bone in children. Nondisplaced fractures may be managed conservatively with immobilization in extension and orthopedic follow-up (Fig. 17). However, any displaced fractures need reduction and immediate orthopedic consultation.

Tibial tuberosity fractures

These are typically avulsion fractures and occur most commonly from strong contraction of the quadriceps against a fixed leg. These injuries typically occur during sports. Displaced injuries need reduction and fixation and require immediate orthopedic consultation.

Tibia and Fibula

Proximal tibial physis and metaphysis fractures

Fractures of the proximal tibial physis are relatively uncommon. The most common potential significant complication is a vascular injury to the popliteal artery, so assessment and documentation of intact pulses and an ankle brachial index is important. In proximal tibial metaphyseal fractures, there is a high risk of drift through healing and growth into a valgus deformity of the knee (Cozen phenomenon), even with proper alignment and immobilization. Orthopedic follow-up for these fractures is therefore essential.

Fractures of the tibia and fibula diaphyses

Fractures of the shaft of tibia and fibula are common in children, and one of the most common fractures in younger children is the toddler's fracture.[50] This is an isolated minimally displaced (<2 mm) spiral/oblique fracture of the distal tibia in a child

Fig. 17. Tibial spine fracture identified by the arrow. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

9 months to 4 years.[51] Parents report that the child is limping or refusing to bear weight for no apparent reason or after seemingly insignificant trauma. The specific mechanism is often external rotation of the foot with the knee flexed. Clinically, there is usually pain with palpation and rotation of the distal tibia, although swelling or tenderness may be minimal or absent. Obtain radiographs of the tibia and fibula in the limping toddler, even in the absence of physical examination findings. Radiographically, a fracture line may be noticed at the distal third of the tibial shaft (**Fig. 18**). At times, initial standard plain radiographs may be normal. In these cases, oblique views may show a fracture line when standard views are negative. If a toddler's fracture is clinically suspected and initial radiographs are negative, splint immobilization and no immobilization are both management options with follow-up in one week for repeat radiographs.[52–54] If radiographs are negative, and there is also the absence of a traumatic history, clinicians are encouraged to rule out other possible diagnoses that could lead to difficulty weight bearing in a young child. For radiologically evident fractures, there is currently a wide practice variation on the need for immobilization. Options include immobilization of the injured leg in a long leg splint, removable prefabricated device or above/below knee cast.[52,54] The most commonly applied standard is a long leg splint in the ED followed by an above or below knee cast placed in the orthopedics clinic.[52,54]

In older children, if the fracture is minimally displaced and there is no evidence of compartment syndrome, immobilize in a long leg posterior splint and arrange orthopedic follow-up. However, if there is >10° of angulation in any plane, orthopedic consultation and reduction may be indicated. Where there is a high-energy injury, if the limb was in highly metabolic state at the time of injury (eg, taking part in sports), or if there is any element of a crush injury, then there is a risk of compartment syndrome, and the patient may need to be admitted for several examinations.

Fig. 18. Spiral fracture of the distal tibia. The arrow points to the lucency in the distal third of the tibial. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

Ankle

Pediatric ankle injuries are common, but only approximately 12% of ankle injuries result in ankle fractures.[55] To avoid unnecessary radiographs in children with ankle injuries, clinical decision rules may be applied to determine which children's injuries benefit from radiographs. In a multicenter analysis, implementation of the Low-Risk Ankle Rule (**Fig. 19**)[55] safely reduced radiographs by 22% and demonstrated significant health care cost savings.[56,57] The Ottawa Ankle Rules have also been validated in children.[58–60] However, although these rules are highly sensitive, they only reduce radiographs by approximately 10%.[56] Once plain radiographs are considered necessary, standard views include anteroposterior, lateral, and oblique views. Distal tibia growth plate fractures may be at higher risk of complications, and as such additional imaging techniques such as CT and MRI can be used to help define the degree of displacement.

Distal fibula ankle fractures

These are the most common lower extremity injuries in children older than 5 years. The key fractures to consider in this location are Salter-Harris I, II, and fibular avulsion fractures. Children who present with lateral ankle injuries and no radiographic evidence of a fracture are commonly diagnosed with a distal fibular Salter-Harris I physeal fracture. However, in a recent study that included 135 skeletally immature children with this clinical scenario, MRI demonstrated that only 4 (3%) of these children had Salter-Harris I fractures of the distal fibula, 2 of which were partial injuries, and all children had ligamentous injuries or bony contusions.[61] Thus, radiograph-negative lateral ankle injuries in children are more appropriately diagnosed with ligamentous injuries and managed with a removable ankle brace and self-regulated return to activities.[62,63]

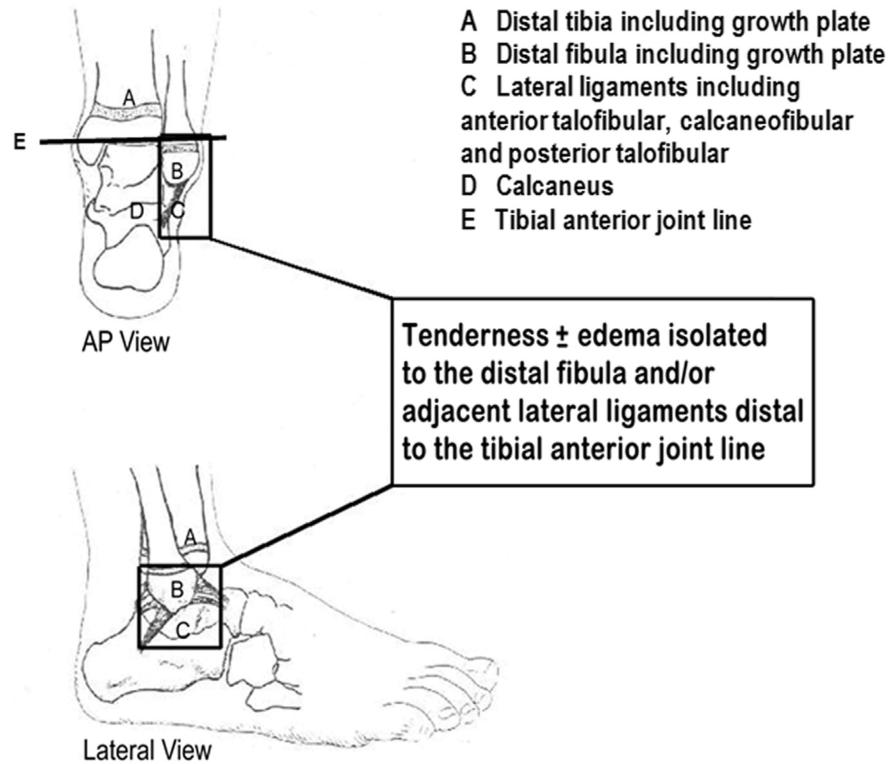

Fig. 19. The low-risk ankle rule. AP, anteroposterior. (*Modified from* Hoppenfeld S, Hutton R, Thomas H (Eds.). Physical examination of the foot and ankle: physical examination of the spine and extremities. Appleton-Century-Crofts: New York; pp. 217-222.)

As such, routine orthopedic follow-up is not necessary for these cases and can be reserved for cases not recovering as expected.

Salter-Harris Type II (**Fig. 20**) and distal fibular avulsion fractures occur with an inversion injury. In general, when there is no significant displacement, these fractures may be managed by immobilization in a weight-bearing cast or commercial immobilizer, and orthopedic follow-up is usually not necessary.[62,63] In isolation, distal fibular Salter-Harris III-V fractures are very rare. If suspected, consult orthopedics for management.

Distal tibia ankle fractures

Salter-Harris I and II fractures of the distal tibia are the most common fractures of the distal tibia. They can be managed with immobilization and follow-up in an orthopedic clinic, but displaced fractures may require closed reduction. Salter-Harris III fractures account for approximately 25% of distal tibia fractures and may need open reduction if there is any significant displacement. Tillaux fracture is a Salter-Harris Type III fracture of the anterolateral portion of the distal tibia (see **Fig. 3**). Treatment is surgical reduction in most cases that demonstrate displacement, and thus, urgent orthopedic consultation is indicated. Salter-Harris IV fractures (see **Fig. 4**) include the triplane fracture, which involves fractures in the sagittal, coronal, and transverse planes, resulting in multiple fracture fragments. CT helps delineate the extent of the joint

Fig. 20. Distal fibular Salter-Harris II. The arrow points to metaphyseal fracture that extends into the growth plate. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

surface injury in both Salter-Harris Type III and IV ankle fractures. The management is often urgent surgical reduction.

Foot and Toe

The lack of ossification of the foot bones in younger children makes fractures in this area rare. As ossification increases with age, fractures become more common, but significant injuries are still unusual. Fractures of the mid- and hindfoot are rare, and usually result from a fall. They can often be managed with a splint and orthopedic follow-up. Fractures of the metatarsals and phalanges are relatively common in children and typically result from a direct blow from a falling object. Most nondisplaced fractures of the metatarsals and phalanges can be managed by immobilization in a posterior short-leg splint and orthopedic follow-up. Significantly displaced fractures of the metatarsals and phalanges, as well as those of the great toe that have intra-articular involvement, may require fixation, although this can typically be done on an outpatient basis. Fractures of the base of the fifth metatarsal are common with inversion injuries of the ankle, and thus the evaluation of ankle injuries should, therefore, include radiographs of the foot when there is tenderness over the fifth metatarsal. The immature skeleton consists of an ossification center lateral to the base of the fifth metatarsal (**Fig. 21**) to which the peroneus brevis tendon attaches. This ossification center may be confused with a fracture, although an avulsion fracture at this site can also occur and presents with point tenderness and displacement of the ossification center. Immobilization and orthopedic follow-up are recommended. Crush injuries to the foot may cause vascular compromise and compartment syndrome, and thus urgent orthopedic consultation is indicated.

MISSING PEDIATRIC FRACTURES IN THE EMERGENCY DEPARTMENT

One factor that may lead to missing a fracture is the extent of the history and physical examination obtained. In children, getting detailed mechanisms to help elucidate the type of injury is often not possible; further, younger children are often challenging to examine. Thus, in cases in which history or physical examination is limited, we encourage physicians to have a very low threshold to obtain radiographs. If an older child is cooperative and able to localize pain, validated clinician decision rules can be used to determine the need for imaging.[31,49,56] However, these rules are only to be used after a comprehensive physical examination is completed and are not meant to replace the physical examination. Using a rule-based physical examination can lead to missing important pathology. Other factors that may lead to missing a fracture in the ED are related to cognitive biases that impact how we process information and make clinical decisions.[64] A low clinical suspicion of a fracture on history and physical can bias the physician such that their ability to see the fracture on the radiograph may be compromised. The classic example is a subtle Tillaux fracture. On physical

Fig. 21. A normal ossification center lateral to the base of the fifth metatarsal. The arrow points to the ossification center. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

examination, the ankle demonstrates soft tissue swelling predominantly over the distal fibula: a clinical presentation similar to an ankle sprain, especially because this fracture typically occurs in older children (12–14 years). As such, the clinician reviews the radiograph with a low suspicion for a fracture and misses the more subtle radiographic presentations of this fracture. Careful examination of the anterior joint line, in this case, would demonstrate significant tenderness, cueing the physician to examine this area of the radiograph more carefully.

Another common cognitive bias is search satisficing[64]; heed the saying, "the most commonly missed fracture is the second fracture." As we reviewed previously, this can occur in Monteggia fractures where the clinician identifies the ulnar fracture and then misses the more serious radial head dislocation (see **Fig. 13**). This can also result in underestimating the seriousness of a fracture. For example, the distal radius Salter-Harris II fracture is often misdiagnosed as a distal radius buckle fracture in the ED. In this case, clinicians note the buckling of the cortex and fail to continue examining the radiograph, missing the extension of the fracture into the growth plate or any associated displacement (**Fig. 22**).

It is important for clinicians to remember that pediatric fractures are not always evident on the initial radiographs. Thus, in cases of high clinical suspicion for a fracture, even in the absence of a radiograph-visible fracture, the child should be immobilized and referred for orthopedic follow-up. Nevertheless, the most common reason for missing a fracture is due to deficiencies in physician interpretation skill of pediatric musculoskeletal images, and error rates have been reported to occur in

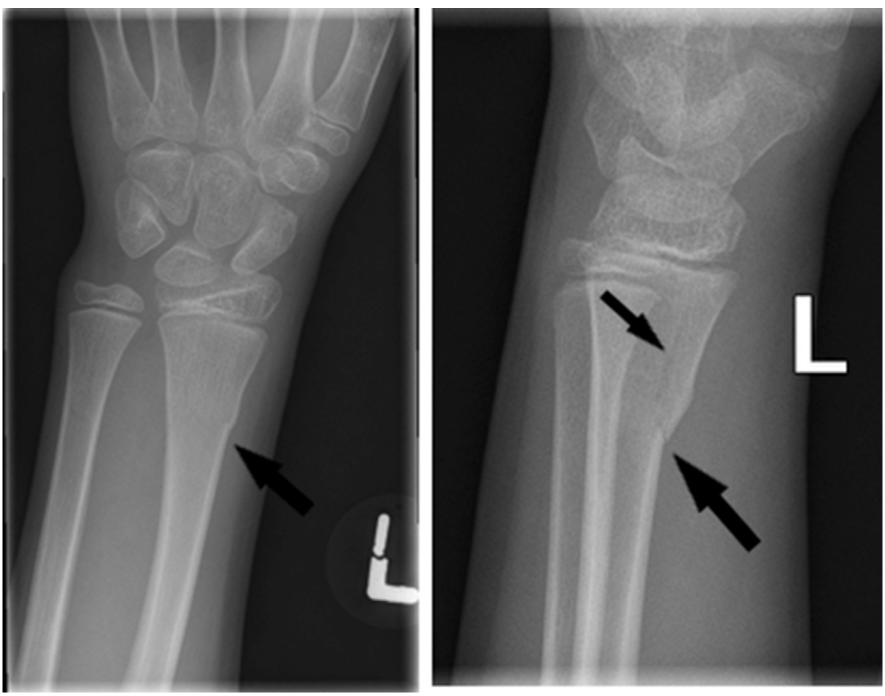

Fig. 22. Left, a subtle Salter-Harris II fracture of the distal radius (*arrow*). Right, the large arrow points to the buckling of the cortex and clinicians may stop looking and miss the more subtle extension into the growth plate indicated by the smaller arrow. (*Courtesy of* K. Boutis, MD, Toronto, ON.)

3% to 15% of pediatric musculoskeletal images.[65] Although most imaging over-reads by a radiologist may identify errors, errors are often not reported until after the patient has left the ED, which can lead to other unnecessary visits for the patient and health care system and medico-legal complaints.[66] In this scenario, it would be optimal to increase physician skill via education. Although there are many electronic resources that cover the approach to pediatric musculoskeletal images, there is currently only one that allows the deliberate active practice of cases. ImageSim (www.imagesim.com) is an evidence-based on-line learning platform that includes a course in pediatric musculoskeletal radiograph interpretation where the clinician can practice on as many as 2100 cases and receive feedback with every case completed.[65,67–69] As an additional measure, hospital-based quality assurance programs that include imaging over-reads by radiologists within 48 hours is highly recommended.

SUMMARY

Fractures are a common presenting complaint to the ED. However, relative to adults, the unique healing abilities of children allow for a lower rate of long-term fracture-related complications such as malunion, disability, arthritis. The ED management strategy of a specific pediatric fractures considers several factors. These include (but are not limited to) the age of the patient, open or closed fracture, radiographic features (location and degree of displacement/angulation of the fracture), risk of growth arrest, and/or concerns about neurovascular compromise or compartment syndrome. Minimal intervention strategies that focus on symptom relief and patient-guided return to activities are appropriate for uncomplicated mid-clavicular fractures, distal radius buckle fractures, undisplaced distal fibular Salter-Harris I, II and avulsion fractures. Nevertheless, before committing to a management strategy, it is essential that ED physicians create individual and system-level conditions to correctly diagnose the injury on the radiograph. These can include being aware of cognitive biases that lead to radiograph interpretation error, individual physician education, and radiology quality assurance of ED radiograph interpretations within 48 hours.

REFERENCES

1. Salter RB, Harris WR. Injuries involving the epiphyseal plate. J Bone Joint Surg 1963;45(3):587–622.
2. Bachman D, Santora S. Orthopedic trauma. In: Fleisher GL, Henretig F, Ruddy R, et al, editors. Textbook of pediatric emergency medicine. 4th edition. Philadelphia: Lippincott Williams & Wilkins; 2000. p. 1435–77.
3. Wilkins KE. Principles of fracture remodeling in children. Injury 2005;36(Suppl 1):A3–11.
4. Adamich J, Howard A, Camp M. Do all clavicle fractures in children need to be managed by orthopedic surgeons? Pediatr Emerg Care 2018;34(10):706–10.
5. Vander Have KL, Perdue AM, Caird MS, et al. Operative versus nonoperative treatment of midshaft clavicle fractures in adolescents. J Pediatr Orthop 2010;30(4):307–12.
6. Shah RR, Kinder J, Peelman J, et al. Pediatric clavicle and acromioclavicular injuries. J Pediatr Orthop 2010;30:S69–72.
7. Gladstein AZ, Schade AT, Howard AW, et al. Reducing resource utilization during non-operative treatment of pediatric proximal humerus fractures. Orthop Traumatol Surg Res 2017;103(1):115–8.

8. Chaus GW, Carry PM, Pishkenari AK, et al. Operative versus nonoperative treatment of displaced proximal humeral physeal fractures: a matched cohort. J Pediatr Orthop 2015;35(3):234–9.
9. Popkin CA, Levine WN, Ahmad CS. Evaluation and management of pediatric proximal humerus fractures. J Am Acad Orthop Surg 2015;23(2):77–86.
10. Caviglia H, Garrido CP, Palazzi FF, et al. Pediatric fractures of the humerus. Clin Orthop Relat Res 2005;(432):49–56.
11. Shaw BA, Murphy KM, Shaw A, et al. Humerus shaft fractures in young children: accident or abuse? J Pediatr Orthop 1997;17(3):293–7.
12. Thomas SA, Rosenfield NS, Leventhal JM, et al. Long-bone fractures in young children: distinguishing accidental injuries from child abuse. Pediatrics 1991; 88(3):471–6.
13. Jacoby SM, Herman MJ, Morrison WB, et al. Pediatric elbow trauma: an orthopaedic perspective on the importance of radiographic interpretation. Semin Musculoskelet Radiol 2007;11(1):48–56.
14. Shrader MW, Campbell MD, Jacofsky DJ. Accuracy of emergency room physicians' interpretation of elbow fractures in children. Orthopedics 2008;31(12) [pii:orthosupersite.com/view.asp?rID=34697].
15. Dowling S, Farion K, Clifford T. Comparison views to diagnose elbow injuries in children: a survey of Canadian non-pediatric emergency physicians. CJEM 2005;7(4):237–40.
16. Ballal MS, Garg NK, Bass A, et al. Comparison between collar and cuffs and above elbow back slabs in the initial treatment of Gartland type I supracondylar humerus fractures. J Pediatr Orthop B 2008;17(2):57–60.
17. Oakley E, Barnett P, Babl FE. Backslab versus nonbackslab for immobilization of undisplaced supracondylar fractures: a randomized trial. Pediatr Emerg Care 2009;25(7):452–6.
18. Hwang RW, Bae DS, Waters PM. Brachial plexus palsy following proximal humerus fracture in patients who are skeletally immature. J Orthop Trauma 2008;22(4): 286–90.
19. Wu J, Perron AD, Miller MD, et al. Orthopedic pitfalls in the ED: pediatric supracondylar humerus fractures. Am J Emerg Med 2002;20(6):544–50.
20. Ladenhauf HN, Schaffert M, Bauer J. The displaced supracondylar humerus fracture: indications for surgery and surgical options: a 2014 update. Curr Opin Pediatr 2014;26(1):64–9.
21. Bast SC, Hoffer MM, Aval S. Nonoperative treatment for minimally and nondisplaced lateral humeral condyle fractures in children. J Pediatr Orthop 1998; 18(4):448–50.
22. Knapik DM, Gilmore A, Liu RW. Conservative management of minimally displaced (</=2 mm) fractures of the lateral humeral condyle in pediatric patients: a systematic review. J Pediatr Orthop 2017;37(2):e83–7.
23. Beaty JH JR, K. The elbow: physeal fractures, apophyseal injuries of the distal humerus, avascular necrosis of the trochlea, and T-condylar fractures. In: Rockwood CA, Wilkins KE, Beaty JH, et al, editors. Rockwood and Wilkins' fractures in children. 5th edition. Philadelphia: Lippincott Williams & Wilkins; 2001. p. 625.
24. Tarallo L, Mugnai R, Fiacchi F, et al. Pediatric medial epicondyle fractures with intra-articular elbow incarceration. J Orthop Traumatol 2015;16(2):117–23.
25. Dodds SD, Flanagin BA, Bohl DD, et al. Incarcerated medial epicondyle fracture following pediatric elbow dislocation: 11 cases. J Hand Surg Am 2014;39(9): 1739–45.

26. Caterini R, Farsetti P, D'Arrigo C, et al. Fractures of the olecranon in children. Long-term follow-up of 39 cases. J Pediatr Orthop B 2002;11(4):320–8.
27. Zimmerman RM, Kalish LA, Hresko MT, et al. Surgical management of pediatric radial neck fractures. J Bone Joint Surg Am 2013;95(20):1825–32.
28. Krul M, van der Wouden JC, Kruithof EJ, et al. Manipulative interventions for reducing pulled elbow in young children. Cochrane Database Syst Rev 2017;(7):CD007759.
29. Bexkens R, Washburn FJ, Eygendaal D, et al. Effectiveness of reduction maneuvers in the treatment of nursemaid's elbow: a systematic review and meta-analysis. Am J Emerg Med 2017;35(1):159–63.
30. Hedstrom EM, Svensson O, Bergstrom U, et al. Epidemiology of fractures in children and adolescents. Acta Orthop 2010;81(1):148–53.
31. Mulders MAM, Walenkamp MMJ, Slaar A, et al. Implementation of the Amsterdam pediatric wrist rules. Pediatr Radiol 2018;48(11):1612–20.
32. Mehlman C, Wall E. Injuries to the shafts of the radius and ulna. In: Beaty JH, Kasser JR, Rockwood CA, et al, editors. Rockwood and Wilkins' fractures in children. 6th ediiton. Philadelphia: Lippincott Williams & Wilkins; 2006. p. 400.
33. Mabrey JD, Fitch RD. Plastic deformation in pediatric fractures: mechanism and treatment. J Pediatr Orthop 1989;9(3):310–4.
34. Boutis K, Willan A, Babyn P, et al. Cast versus splint in children with minimally angulated fractures of the distal radius: a randomized controlled trial. CMAJ 2010;182(14):1507–12.
35. Al-Ansari K, Howard A, Seeto B, et al. Minimally angulated pediatric wrist fractures: is immobilization without manipulation enough? CJEM 2007;9(1):9–15.
36. Koelink E, Schuh S, Howard A, et al. Primary care physician follow-up of distal radius buckle fractures. Pediatrics 2016;137(1). https://doi.org/10.1542/peds.2015-2262.
37. Jiang N, Cao ZH, Ma YF, et al. Management of pediatric forearm torus fractures: a systematic review and meta-analysis. Pediatr Emerg Care 2016;32(11):773–8.
38. Ben-Yakov M, Boutis K. Buckle fractures of the distal radius in children. CMAJ 2016;188(7):527.
39. Mehlman CT. Home removal of a backslab 3 weeks after buckle fracture of the distal radius was as safe as removal at a fracture clinic. J Bone Joint Surg 2002;84(5):883.
40. Symons S, Rowsell M, Bhowal B, et al. Hospital versus home management of children with buckle fractures of the distal radius. A prospective, randomised trial. J Bone Joint Surg Br 2001;83(4):556–60.
41. Hamilton TW, Hutchings L, Alsousou J, et al. The treatment of stable paediatric forearm fractures using a cast that may be removed at home: comparison with traditional management in a randomised controlled trial. Bone Joint J 2013;95-B(12):1714–20.
42. Jauregui JJ, Seger EW, Hesham K, et al. Operative management for pediatric and adolescent scaphoid nonunions: a meta-analysis. J Pediatr Orthop 2019;39(2):e130–3.
43. Shaterian A, Santos PJF, Lee CJ, et al. Management modalities and outcomes following acute scaphoid fractures in children: a quantitative review and meta-analysis. Hand (N Y) 2019;14(3):305–10.
44. Lankachandra M, Wells CR, Cheng CJ, et al. Complications of distal phalanx fractures in children. J Hand Surg Am 2017;42(7):574.e1–6.
45. Grisoni N, Connor S, Marsh E, et al. Pelvic fractures in a pediatric level I trauma center. J Orthop Trauma 2002;16(7):458–63.

46. Capra L, Levin AV, Howard A, et al. Characteristics of femur fractures in ambulatory young children. Emerg Med J 2013;30(9):749–53.
47. Wood JN, Fakeye O, Mondestin V, et al. Prevalence of abuse among young children with femur fractures: a systematic review. BMC Pediatr 2014;14:169.
48. Lieber J, Schmittenbecher P. Developments in the treatment of pediatric long bone shaft fractures. Eur J Pediatr Surg 2013;23(6):427–33.
49. Vijayasankar D, Boyle AA, Atkinson P. Can the Ottawa knee rule be applied to children? A systematic review and meta-analysis of observational studies. Emerg Med J 2009;26(4):250–3.
50. Adamich JS, Camp MW. Do toddler's fractures of the tibia require evaluation and management by an orthopaedic surgeon routinely? Eur J Emerg Med 2018;25(6): 423–8.
51. Dunbar JS, Owen HF, Nogrady MB, et al. Obscure tibial fracture of infants–the Toddler's fracture. J Can Assoc Radiol 1964;15:136–44.
52. Seguin J, Brody D, Li P. Nationwide survey on current management strategies of toddler's fractures. CJEM 2018;20(5):739–45.
53. Bauer JM, Lovejoy SA. Toddler's fractures: time to weight-bear with regard to immobilization type and radiographic monitoring. J Pediatr Orthop 2019;39(6): 314–7.
54. Schuh AM, Whitlock KB, Klein EJ. Management of Toddler's fractures in the pediatric emergency department. Pediatr Emerg Care 2016;32(7):452–4.
55. Boutis K, Komar L, Jaramillo D, et al. Sensitivity of a clinical examination to predict need for radiography in children with ankle injuries: a prospective study. Lancet 2001;358(9299):2118–21.
56. Boutis K, Grootendorst P, Willan A, et al. Effect of the Low Risk Ankle Rule on the frequency of radiography in children with ankle injuries. CMAJ 2013;185(15): E731–8.
57. Boutis K, von Keyserlingk C, Willan A, et al. Cost consequence analysis of implementing the low risk ankle rule in emergency departments. Ann Emerg Med 2015; 66(5):455–63.e4.
58. Dowling S, Spooner CH, Liang Y, et al. Accuracy of Ottawa Ankle Rules to exclude fractures of the ankle and midfoot in children: a meta-analysis. Acad Emerg Med 2009;16(1):1–11.
59. Gravel J, Hedrei P, Grimard G, et al. Prospective validation and head-to-head comparison of 3 ankle rules in a pediatric population. Ann Emerg Med 2009; 54(4):534–40.
60. Plint AC, Bulloch B, Osmond MH, et al. Validation of the Ottawa Ankle Rules in children with ankle injuries. Acad Emerg Med 1999;6(10):1005–9.
61. Boutis K, Plint A, Stimec J, et al. Radiograph-negative lateral ankle injuries in children: occult growth plate fracture or sprain? JAMA Pediatr 2016;170(1):e154114.
62. Barnett PL, Lee MH, Oh L, et al. Functional outcome after air-stirrup ankle brace or fiberglass backslab for pediatric low-risk ankle fractures: a randomized observer-blinded controlled trial. Pediatr Emerg Care 2012;28(8):745–9.
63. Boutis K, Willan AR, Babyn P, et al. A randomized, controlled trial of a removable brace versus casting in children with low-risk ankle fractures. Pediatrics 2007; 119(6):e1256–63.
64. Daniel M, Khandelwal S, Santen SA, et al. Cognitive debiasing strategies for the emergency department. AEM Educ Train 2017;1(1):41–2.
65. Lee MS, Pusic M, Carriere B, et al. Building emergency medicine trainee competency in pediatric musculoskeletal radiograph interpretation: a multicenter prospective cohort study. AEM Educ Train 2019;3(3):269–79.

66. Selbst SM, Friedman MJ, Singh SB. Epidemiology and etiology of malpractice lawsuits involving children in US emergency departments and urgent care centers. Pediatr Emerg Care 2005;21(3):165–9.
67. Boutis K, Pecaric M, Pusic M. Using signal detection theory to model changes in serial learning of radiological image interpretation. Adv Health Sci Educ Theory Pract 2010;15:647–58.
68. Pusic M, Pecaric M, Boutis K. How much practice is enough? Using learning curves to assess the deliberate practice of radiograph interpretation. Acad Med 2011;86(6):731–6.
69. Pusic MV, Andrews JS, Kessler DO, et al. Determining the optimal case mix of abnormals to normals for learning radiograph interpretation: a randomized control trial. Med Educ 2012;46(3):289–98.