Identifying and managing physeal injuries in the upper extremity

Understanding bone growth patterns in young patients and knowing what to look for on imaging are key to determining the best approach to these injuries.

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Diagnosis and management of growth plate injuries in the skeletally immature patient can be challenging. Inability to visualize the injury on a radiograph and incomplete understanding of normal bone development can contribute to diminished recognition of these injuries. Proper identification is a vital first step to prevent devastating outcomes in limb form and function. The goal of this review is to provide a thorough understanding of the physis and the types of physeal injuries, the keys to radiographic interpretation, and management strategies.

GROWTH PLATE ANATOMY

The skeleton of a 10-week-old fetus is 100% cartilage.[1] At birth, bone mineralization is approximately 85% of adult composition,[1] but a large portion of cartilage remains to allow for growth. Growth in long bones occurs through endochondral ossification, the process by which a cartilage progenitor is converted to bone. These precursors to bone, which reside between ossification centers in the diaphysis and distal ends of long bones, ultimately comprise the epiphyseal, or growth, plate.

By the time an infant is 3 months old, the first growth plate to form (the proximal humerus) can be well-visualized on radiographs of the upper extremity.[2] Each plate is seen as a discrete linear lucency between the metaphysis (toward the shaft) and the epiphysis (toward the joint). Over time, bone growth is seen radiographically to progress from the metaphysis toward the epiphysis, but cell differentiation occurs in the opposite direction. Chondrocytes travel through four distinct layers of the growth plate until they mature and push the entire physis distally to continue longitudinal growth. The four layers of differentiation include: the *resting zone*, the *proliferative zone*, the *hypertrophic zone*, and the *provisional calcification zone* (Figure 1). Most of the growth plate is avascular, but the epiphyseal vascular system penetrates the resting zone and supplies the proliferative zone.[3,4]

PHYSIS PHYSIOLOGY

The **resting zone** is epicentral to the ossific nucleus and comprises a large extracellular matrix with inert chondrocytes dispersed randomly throughout. The matrix contains an array of proteoglycans and collagen fibrils that suppress the deposition of calcium.[3,4]

Chondrocytes migrate from the resting zone into the **proliferative zone**, where the cells begin to organize and condense tightly into longitudinal columns. Accelerated replication further reduces the matrix volume, leading to deformation and flattening of the cells. Hormones, growth factors, and rich vascularization to this area help to mediate the process.[3,4]

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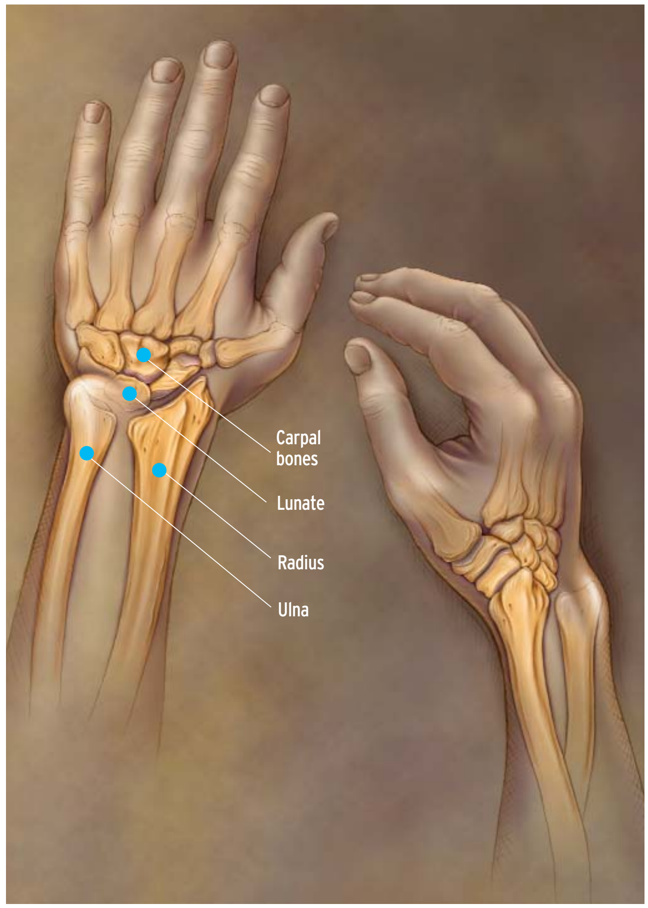

Madelung's deformity, an inheritable skeletal dysplasia

As the proliferative zone advances, the cell bed left behind continues to develop and is referred to as the **hypertrophic zone**. Here, the environment becomes progressively more hypoxic, forcing the cells into anaerobic metabolism and creating an imbalance in intracellular calcium concentrations. Calcium is released from the cells and saturates the extracellular matrix. Collagen and proteoglycans are now compelled to interact with calcium to form a crystalline structure and solid bone. The exact mechanism of bone formation is still debated.[3,4]

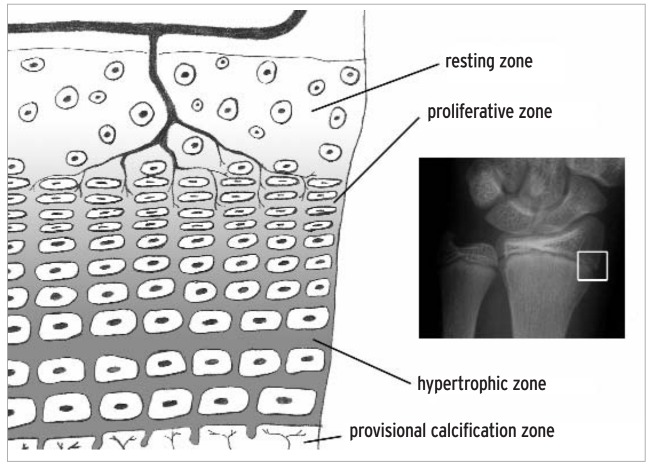

FIGURE 1. Zones of the physis

CLASSIFICATION OF INJURY

In 1963, Salter and Harris evaluated and categorized growth plate fractures.[5] The Salter-Harris classification system groups fractures into five types based on the combined involvement of the physis, metaphysis, or epiphysis and an increasing risk of circulatory disruption to the region of growth. **Type I** fractures involve the growth plate only. **Type II** and **type III** fractures represent injuries to the growth plate in addition to a fracture through the metaphysis or epiphysis, respectively. A longitudinal injury through all three structures (epiphysis, growth plate, metaphysis) constitutes a **type IV** fracture. The most severe type (**Salter-Harris V**) results from an impact-type injury, which causes compression and narrowing of the growth plate.[5] This type is at the highest risk for premature closure. A schematic of the Salter-Harris classification is seen in **Figure 2**.

INJURY BY REGION

Most physeal injuries (76%) occur in the upper extremity.[6] The distal radius, phalanges, and distal humerus are the most frequent locations of fractures with growth plate involvement.[6] Understanding the potential for injury in each body region can be useful in diagnosis, since most patients offer nothing more specific than a complaint of joint pain following trauma.

Shoulder Injury to the proximal humeral epiphysis is relatively infrequent (about 2%-3% of all physeal fractures).[6,7] Shoulder injuries are usually type I or type II fractures from a fall or direct trauma. Similar trauma can also result in a glenohumeral joint dislocation or acromioclavicular sprain, so the differential diagnosis should include these injuries. One retrospective series of 57 patients with proximal humeral epiphysis fractures found patients were aged 8 to 15 years at the time of injury. Growth arrest greater than 1 cm was observed in only one patient with a type I or II injury but increased to 8 cm with type III and IV fractures.[7]

Elbow The elbow has six ossification centers, making this joint susceptible to complex patterns of injury. Most fractures occur in the distal humerus and the proximal radius (7% and 4.5% of all physeal injuries, respectively).[6] There are two age ranges during which elbow injuries peak. The first is between the ages of 2 and 8 years, and the second is between the ages of 11 and 15 years. Males account for about 90% of the injuries in the distal humerus.[8] This may be a result of higher activity levels and later physeal closure in males than in females and a relative weakening of the physis at puber-

KEY POINTS

- By the time an infant is 3 months old, the first growth plate in the upper extremity (the proximal humerus) can be well-visualized on radiographs. Over time, bone growth is seen radiographically to progress from the metaphysis toward the epiphysis, but cell differentiation occurs in the opposite direction.
- The wrist is one of the most frequently injured locations on the body. Wrist fracture has a 4.4% chance of premature closure and subsequent radial shortening. Decrease in bone length of less than 1 cm tends not to cause symptoms or affect quality of life.
- Most physeal injuries can be diagnosed and treated with the use of radiographs alone, but if the epiphysis cannot be visualized well and articular involvement is a concern, then MRI is appropriate to evaluate the extent of the fracture. Chronic changes, such as fibrous and bone bridges, are also best visualized with MRI. The greatest role for CT in young patients is in the evaluation of highly complex fractures that require better delineation or for preoperative planning.
- The first problem clinicians encounter with reading radiographs is that physes, apophyses, or overlapping physeal edges are often mistaken for fracture lines. Moreover, the chronology of ossification is often not taken into account. New ossification centers can appear as loose bodies or avulsion fractures, or vice versa, so care should be taken to make a distinction.
- Following trauma, any exquisite palpable pain that is focused over the growth plate should be assumed to result from a Salter-Harris type fracture until proven otherwise. Even if radiographic findings are normal, immobilization for a type I fracture is recommended. If there is any displacement of the fracture fragments, gentle closed reduction may be attempted, but repeated or aggressive manipulation should be avoided for fear of additional iatrogenic physeal injury.

ty.[5,6] Type I and type II injuries are common prior to 4 years of age, but as the growth plate becomes more irregular, developing hills and valleys, with age, supracondylar or type IV condylar fractures become more likely. Lateral condyle fractures comprise 25% of all physeal injuries in the area surrounding the elbow.[8]

Wrist Falls onto an outstretched hand make the wrist one of the most frequently injured locations on the body. The distal radius accounts for 28% of all physeal fractures.[6] The distal ulna accounts for only about 4.5% of injuries.[6] In both the radius and the ulna, 85% to 90% of growth plate fractures are type II, with the remainder usually type I.[6] Although these fractures are given a low-level classification, they still have a 4.4% chance of premature closure and subsequent radial shortening.[9] A decrease in bone length of less than 1 cm tends not to cause symptoms or interfere with the patient's quality of life.[9]

Hand The most interactive and vulnerable part of the upper extremity, the hand has a high rate of injury. The hand accounts for 30% of all growth plate injuries, with 26% occurring in the phalanges alone.[6,10] Fischer and McElfresh reviewed in detail 1,021 patients with finger fractures and found that 36% of their patients had physeal involvement.[10] They also described the typical patient as male (65%), adolescent (61%), and having an injury related to sports (59%).[10] Salter-Harris type II fractures accounted for almost all physeal injuries at the metacarpals and proximal phalanges. Injuries at the middle and distal phalanges were type I through type III.

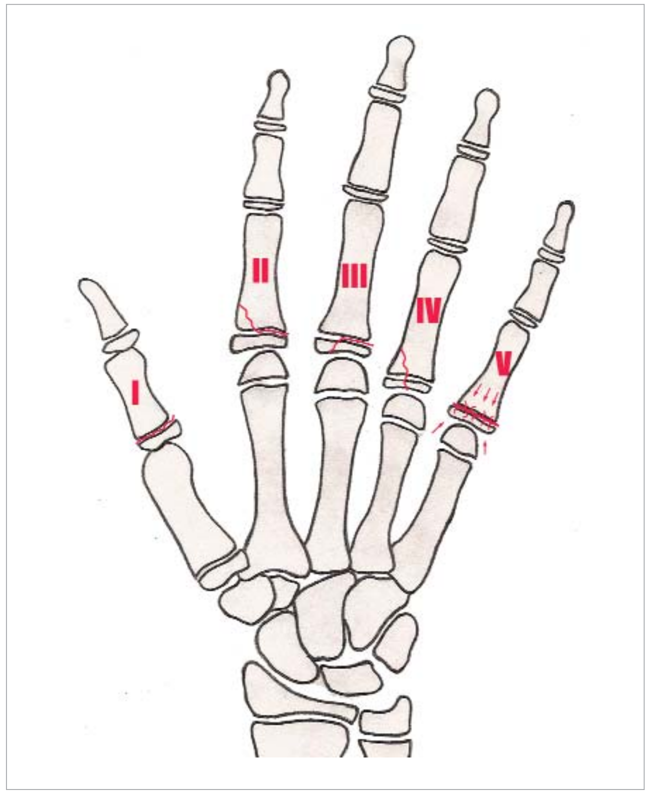

FIGURE 2. Salter-Harris classification

FIGURE 3. Salter-Harris type I injury with physis widening is shown at left. Recovery of growth after treatment with visible Harris growth arrest line is seen at right.

IMAGING STUDIES

Radiography Radiologic assessment of all suspected traumatic injuries should begin with plain films of the affected region. If pain is present at adjacent body parts, consider the "joint above/joint below" credo and order radiographs accordingly. Obtain oblique films if you suspect a growth plate injury, as they often reveal pathology not seen on straight plane projections. Stress views should be avoided if possible. The physis should be scrutinized for radiographic signs of disruption, which include evidence of displacement, apparent widening of the plate (**Figure 3**), dull and indiscernible metaphyseal or epiphyseal borders, and small bone avulsions within the physis known as *lamellar fragments* (**Figure 4**).[11]

Normal anatomic relationships should also be confirmed where multiple joints are in close proximity. At the wrist, the ulnar head should be even with the distal radius epiphyseal plate. The relationship of the distal radius to the carpals can be difficult to assess, depending on the number of ossific carpal bones and the extent of ossification. Ossification of the scaphoid occurs in a distal to proximal direction, coinciding with its retrograde vascularity, and can be misconstrued as scapholunate ligament disruption because of pseudowidening. On a true lateral projection of the elbow, ensure that the radial head is pointing to the center of the capitellum and that the capitellum is oriented correctly on the distal humerus. The latter can be determined by extending a line from the anterior border of the humerus through the capitellar

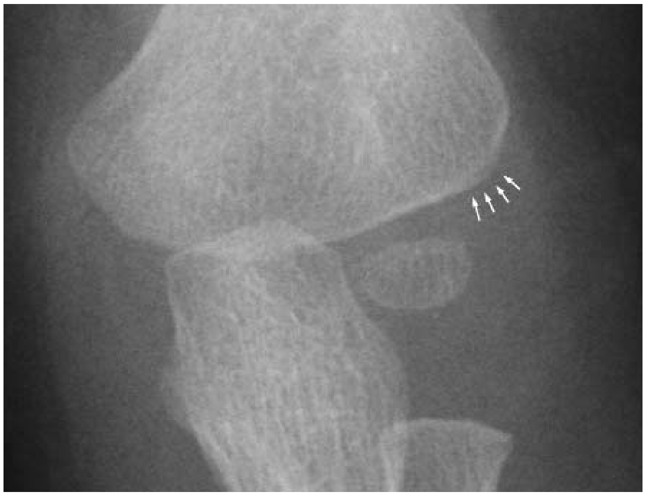

FIGURE 4. Metaphyseal bone chip in nondisplaced distal humerus fracture

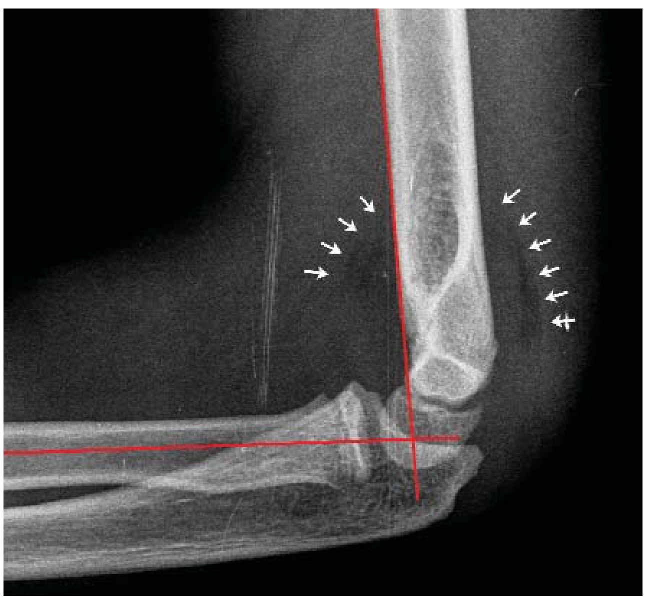

FIGURE 5. Radiocapitellar and anterior humeral lines bisect the capitellum. Subtle anterior and posterior fat pads are indicated by arrows.

ossific nucleus, which should be transected equally (Figure 5). If either of the aforementioned relationships is not as described, suspect injury to the proximal radius or humeral condyles, respectively.

A *fat pad sign*, or *sail sign*, may also be helpful in discovering intra- and periarticular fractures about the elbow. The fat pad sign presents as a triangular lucency just anterior or just posterior to the distal humerus on a lateral radiograph and represents elevation of the soft tissue from the bone secondary to an intracapsular effusion (Figure 5). An anterior fat pad sign is a normal finding and not strongly associated with fracture, but posterior fat pad elevation is abnormal and has been found to correlate with fracture 80% of the time.[12] The absence of a posterior fat pad sign does not exclude fracture, as the capsule may be torn or the fracture may extend outside the joint. Harrison and colleagues looked at how to evaluate medial humeral condyle fractures, which can be largely extra-articular, in the skeletally immature patient. Their study showed that the combination of a metaphyseal bone chip and considerable soft-tissue swelling was highly associated with these fracture types, but the fat pad could be either present or absent.[13]

MRI Most physeal injuries can be diagnosed and treated with the use of radiographs alone, but if the epiphysis cannot be visualized well and articular involvement is a concern, then MRI is appropriate to evaluate the extent of the fracture. This is often the case with suspected fractures of the unossified distal humerus. Chronic changes, such as fibrous and bone bridges, are also best visualized with MRI.[11]

CT The greatest role for CT in patients with growth plate injuries is in the evaluation of highly complex fractures that require better delineation or for preoperative planning.[11]

PITFALLS IN RADIOLOGIC INTERPRETATION

The first problem clinicians encounter with reading radiographs is that physes, apophyses, or overlapping physeal edges are often mistaken for fracture lines. Moreover, the chronology of ossification is often not taken into account. New ossification centers can appear as loose bodies or avulsion fractures, or vice versa, so care should be taken to make a distinction. Various approximations have been made of the typical appearance and development times of ossification centers among children to help with diagnosis, but the most challenging area still proves to be the elbow. A team of researchers led by Cheng looked at the radiographs of 1,577 children ranging in age from 0 to 17 years to determine an age- and gender-appropriate reference for sequential bone formation in the elbow.[14] The first center present on radiography is the capitellum, followed in turn by the radial head, medial epicondyle, olecranon, trochlea, and finally the lateral epicondyle. The accompanying and respective mean ages are 1, 5.5, 6.25, 9.6, 9.9, and 11 years.[14] Females demonstrated earlier ossification than males by 1 to 2 years.[14] Comparison films from the contralateral limb can be useful in establishing baseline anatomy.

CONFOUNDING DIAGNOSES

Madelung's deformity This characteristic deformation of the distal radius growth plate demonstrates increased radial inclination and tilt, leading to dorsal ulna subluxation in combination with volar migration of the lunate. The condition is usually not related to trauma. Instead Madelung's deformity is often associated with dyschondrosteosis, or Leri-Weill syndrome. This inheritable skeletal dysplasia features shortened stature, a short forearm segment, and bilateral Madelung's deformity. Although all three characteristics were initially required to secure the diagnosis, Madelung's deformity alone is often able to identify Leri-Weill syn-

FIGURE 6. Madelung's deformity prior to Vicker's ligament release

FIGURE 7. Madelung's deformity after Vicker's ligament release

drome. The other criteria are now used to determine syndrome severity.[15]

The anatomical cause and deforming force on the distal radius comes from a fibrous band of tissue extending from the lunate to the volar/ulnar aspect of the radial epiphysis. This soft tissue tether, known as *Vickers ligament*, impedes radial-volar growth (Figure 6). If the ligament is released early, the physis can revert to normal growth and alignment[16] (Figure 7). Confusion arises when asymptomatic patients with Madelung's deformity suffer a minor trauma that triggers pain. Subsequent radiographs draw attention to the dramatic radiographic findings, which are misinterpreted as a traumatic bone and growth plate injury.

Infection Another elusive differential diagnosis is infection, which usually manifests with pain. Pain without documented trauma is often categorized as growing pains in the absence of a better diagnosis. Osteomyelitis is rare in young, healthy children, but it is devastating if not recognized and treated early. As pointed out earlier, the growth plate is not well-vascularized. Where the vascular bed terminates near the physis, small capillary loops readily accumulate bacteria as a nidus for infection. Metaphyseal pain during palpation is a common initial manifestation of infection.

Very few studies have looked at children with infection. Tudisco and colleagues followed 26 cases of chronic osteomyelitis for more than 10 years.[17] Patient ages ranged from 4 months to 15 years. Although most of the patients had documented trauma, wounds, or remote-site infections predisposing them to the onset of osteomyelitis, 10 patients had unknown etiologies. Only 11 of the patients presented with fever. All patients received antibiotics; 16 required curettage and eight of those required a second surgery. Fortunately, only four patients had resultant limb shortening and/or angular deformity. Another single-center retrospective review looked only at cases of acute neonatal osteomyelitis that eventually resulted in a growth disturbance.[18] The investigators found six cases at sites other than the hip. Four cases involved the proximal humerus; one, the distal humerus; and one, the distal radius. Interestingly, the growth disturbances did not become apparent until around age 9[18] (Figure 8).

"If a notable deformity in length or angulation does result, surgery may be indicated, especially if there is pain or loss of motion."

TREATMENT

Following trauma, any exquisite palpable pain that is focused over the growth plate should be assumed to result from a Salter-Harris type fracture until proven otherwise. Even if radiographic findings are normal, immobilization for a type I fracture is recommended. If there is any displacement of the fracture fragments, gentle closed reduction may be attempted, but repeated or aggressive manipulation should be avoided for fear of causing additional iatrogenic physeal injury. In the young child with substantial remaining growth, slight deformity can be corrected with osseous remodeling. Eighty percent of growth in the upper extremity occurs in the proximal

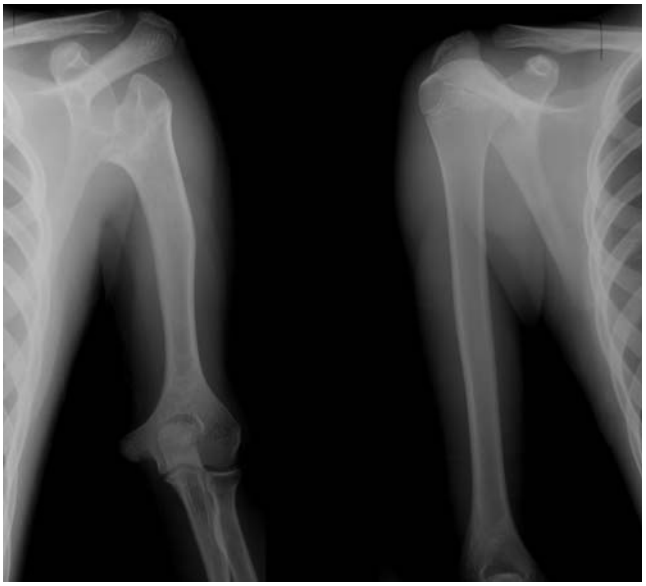

FIGURE 8. Limb shortening in an 11-year-old patient after neonatal infection (left) compared with the opposite unaffected limb (right)

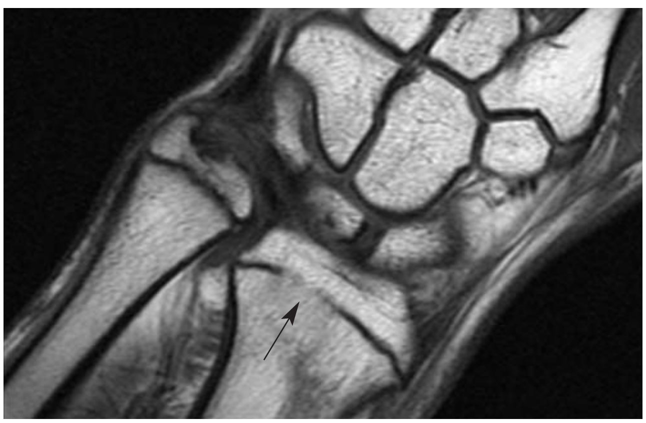

FIGURE 9. Physeal bar on MRI

FIGURE 10. Distal ulna growth arrest and lengthening in a 13-year-old after a dog bite injury and unrecognized fracture

humerus and the distal radius,[19] so these areas accommodate well following deformity (the proximal humerus rarely needs to be reduced unless it is completely displaced[7]). Immobilization should include stabilization of the joint above and below the fracture for 3 to 4 weeks. Children usually do not require 4 to 6 weeks of immobilization because the rich vascularity and increased metabolic activity of the bone lead to accelerated unions. A standard practice is to have the patient follow up 1 week after cast application for repeat radiographs to ensure no loss of reduction. If adequate reduction cannot be attained or remains unstable, then operative fixation should be considered to restore stability and anatomic alignment. Type III and IV fractures are generally treated with percutaneous fixation to address articular involvement. The goal is to realign the physis and restore joint congruity. Postoperative cast immobilization is continued for 4 to 6 weeks.

SEQUELAE

Predicting adverse results from an injury to the physis is difficult, but making the diagnosis, minimizing further trauma, initiating the appropriate treatment, and having extensive follow-up visits can improve outcomes. The patient should return to the office 3 to 6 months after fracture management to ensure recovery of growth plate function. Radiographs are necessary to detect physeal closure and/or bony angulation. An MRI should be ordered if there is concern for a physeal bar, which represents premature closure of a physeal plate (Figure 9). Treatment hinges on the location and site of the bar. Peripheral bars create angular growth deformities, whereas central bars result in shortening over time. If the bar comprises less than 50% of the cross-sectional area of the entire physis and substantial skeletal growth remains, resection of the bar and interpositional fat grafting can be prudent. If the bar is greater than 50% of the physis, then complete closure may be considered to prevent further deformity.[20]

If a notable deformity in length or angulation does result, surgical management may be indicated, especially if there is pain or loss of motion. Performing an epiphysiodesis on the adjacent growth plate in the forearm can keep a proportional relationship between the two bones. When length cannot be regained through manipulation of remaining growth, bony lengthening via distraction osteogenesis is required. In this procedure, an acute angular osteotomy to correct any angular deformity is followed by application of an external fixator device to lengthen the bone. The rate of lengthening is 1 mm per day until the appropriate length is attained. About 6 cm of lengthening is usually attempted in a single procedure, although additional procedures can be performed later. The fixator usually needs to remain in place for 3 to 6 months or until there is adequate consolidation of bone in the defect. An example of lengthening is seen in Figure 10.

CONCLUSION

The rate of injury is high in the upper extremity, specifically in the hand, distal radius, and distal humerus. Diligence is

“Regular follow-up appointments are critical to identify growth disturbances, allow early treatment, and to minimize poor outcomes.”

necessary to recognize and manage growth plate injuries. A thorough knowledge of the radiographic findings and clues to injury and comprehension of the patterns of pediatric development will help ensure accurate diagnosis and establish treatment. MRI is the best advanced imaging study if radiography does not define the fracture well. Most fractures require simple immobilization unless they are displaced, unstable, or intra-articular. Regular follow-up appointments are critical to identify growth disturbances, allow early treatment, and minimize poor outcomes. JAAPA

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