Hand and Wrist Injuries in the Pediatric Athlete

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KEYWORDS

- Gymnast wrist • Scaphoid fracture • Galeazzi fracture • Salter-Harris fracture
- Wrist fracture • Distal radius fracture

KEY POINTS

- Children are increasingly susceptible to adult-type injuries as their sports participation intensifies.
- Intra-articular fractures are unlikely to remodel to within acceptable parameters, and should merit an anatomic or nearly anatomic reduction with stable fixation whenever possible.
- Avoid crossing the physes with anything other than a smooth pin, and avoid multiple passes with the pin.
- Intraphyseal fractures warrant an anatomic reduction within 7 days whenever possible.

INTRODUCTION

Gone are the days when children were allowed free play to develop their motor skills at their own pace. Today, children are being encouraged or even pushed to pursue sports at higher and higher levels at younger and younger ages. As a result, adult-type injuries have become the norm in the pediatric population. One example is scaphoid fractures, which a few decades ago were rare and mostly limited to the distal pole, but are now being seen more frequently and in the same configurations as adult injuries.[1]

The increasing rate of adult-type injuries are in addition to the pediatric-specific injuries more commonly seen, such as physeal injuries and ligamentous avulsions. Children are not just small adults. The growth plate serves as a stress riser in the distal radius and ulna, resulting in injuries that can impact overall growth, joint alignment, and/or differential ulnar/radial length. Ligamentous injuries in children usually present

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as avulsion injuries rather than midsubstance tears. Special attention should be given to understanding the soft tissue attachments of any bony fleck seen on radiographs. In very young children with incompletely ossified epiphyses and carpal bones, avulsions may be purely cartilaginous, making radiographic diagnosis without an MRI or ultrasound impossible. Radiographs weeks to years later may reveal the true extent of the injury as the cartilaginous avulsion ossifies.

There is a bias among orthopedic surgeons to undertreat fractures in children, with the common refrain that "it will just remodel." There is an almost magical belief in the power of a child to erase any evidence of traumatic insult. However, joint dislocations and subluxations do not remodel. Ligamentous injuries likewise do not remodel. It is precisely those ligamentous and soft tissue attachments that may help to guide bony remodeling, and their loss can lead to worsening deformity as the child grows. Galeazzi fractures have been seen that worsen, rather than improve over time because the distal radius becomes untethered from and grows independent of the distal ulna (**Fig. 1**).

Remodeling occurs by two methods: periosteal remodeling and physeal, or Hueter-Volkmann, remodeling (**Fig. 2**). Periosteal remodeling allows straightening of the bone by laying down bone in the gap created by elevated periosteum, while removing bone where the bone no longer sees compressive load. This occurs in response to Wolff's law. Periosteal remodeling does nothing to change where the joint is in space; however. Hueter-Volkmann remodeling occurs at the physis because of the enhanced growth of a partially offloaded physis and the restricted growth of a partially overloaded physis. Ligamentous/tendinous tethering and joint motion work in concert to steer the joint back to where it was in space relative to the native axis of the bone. Lack of motion or, in the case of the wrist, disruption of the triangular fibrocartilage complex (TFCC) can minimize remodeling.

This review examines the most common problematic hand and wrist injuries in pediatric athletes. Special emphasis is placed not on just returning children to their sport quickly, but also on the long-term effects of their injuries and treatment on the long-term life goals of the child.

FINGER AND THUMB INJURIES

Finger and thumb fractures, sprains, and dislocations most commonly occur in ball sports, but is seen in nearly all contact and noncontact sports. Finger proximal

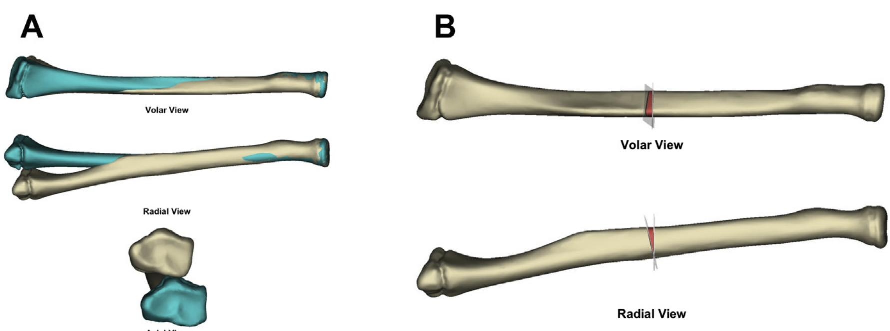

Fig. 1. Galeazzi fracture malunion. A child with a Galeazzi fracture malunion presented with worsening deformity and DRUJ instability. Three-dimensional computer modeling demonstrated the deformity (*A*) and allowed for surgical planning of the osteotomy (*B*). (*Courtesy of* Shriners Hospital for Children Philadelphia.)

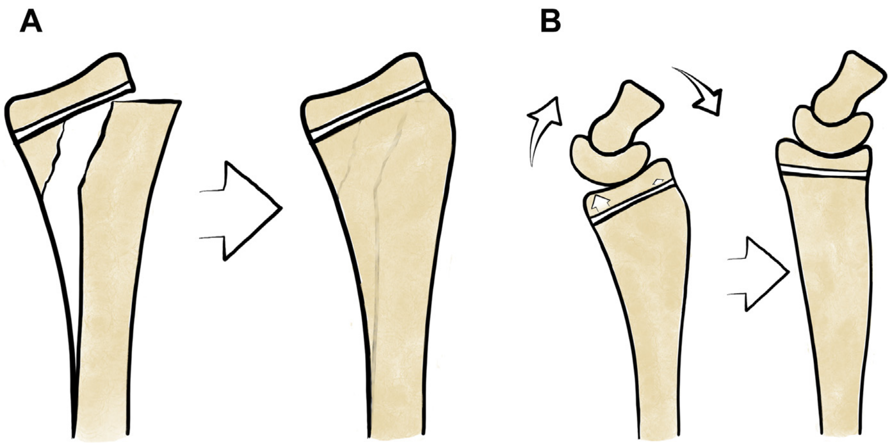

Fig. 2. Periosteal versus Hueter-Volkmann remodeling. Periosteal remodeling, whereby the intact periosteum fills in the gap between the periosteum and the cortical bone while the side with torn periosteum loses bone (*A*), occurs more quickly than Hueter-Volkmann remodeling, where the offloaded physeal cartilage grows faster than the compressed physeal cartilage (*B*). Periosteal remodeling is independent of joint motion, whereas Hueter-Volkmann remodeling requires joint motion and therefore has a greater impact in the direction of joint motion. (*Courtesy of* Dan A. Zlotolow.)

interphalangeal (PIP) joint sprains are perhaps the most common, often from a direct blow with another athlete, the ground, or a ball. The long finger is the most exposed and therefore the most likely to be injured. Examination of the PIP joints is fairly straightforward: (1) radiographs should always be obtained with any PIP joint injury before physical examination because fractures and sprains can look identical clinically, (2) the collateral ligaments and the volar plate should be tested gently for competence, and (3) the integrity of the central slip should be assessed with an Elson test.[2] If there is no fracture and the ligaments and tendons are intact, we buddy tape or strap the injured to its adjacent digit and begin early motion with no period of immobilization to prevent contractures. Ligament injuries require immobilization for up to 4 weeks. Central slip avulsions require at least 6 weeks of immobilization in PIP joint extension with the distal interphalangeal joint free. We use low-temperature plastic to quickly manufacture the splint in the office without the need for a therapist (**Fig. 3**).

Sprains of the distal interphalangeal joint are examined and treated in like manner, with the exception that the terminal tendon replaces the central slip. Acute mallet fractures and deformities without a fracture are treated equally. Late-presenting mallet deformities are also commonly well-managed with just immobilization. Late-presenting fractures require a takedown of the malunion site and pinning if the deformity is not tolerated.

The most common type II phalangeal neck fractures (**Fig. 4**) are most easily treated using the Strauch technique (**Fig. 5**) (https://youtu.be/2ADhL2AOYMU). In their series of four patients, all regained near full painless motion.[3] We attempt an osteoclasis[4] for late injuries up to 2 weeks old or if they remain tender and painful (**Fig. 6**). Older injuries are effectively healed and are mobilized after 4 weeks from injury. There is evidence that malunions remodel if more than 2 years of growth remain. All eight patients in one study regained full motion after 1 year.[5] Although the sagittal deformities completely remodeled in all patients, coronal deformities showed less remodeling potential, correcting only 7° on average.

Fig. 3. Finger splinting. Finger splints are easily manufactured in the office using low-temperature thermoplastic material. (*Courtesy of* Steven J. Thompson and Dan A. Zlotolow.)

Intercondylar fractures are nearly always unstable and require fixation. Open treatment is risky because of the high risk of avascular necrosis of the condyles. Closed reduction and pinning is therefore recommended. A towel clamp or pointed reduction forceps is applied above the midaxial line to effect a reduction while minimizing neurovascular injury risk. Fingertrap traction also is helpful. There should be a minimum of

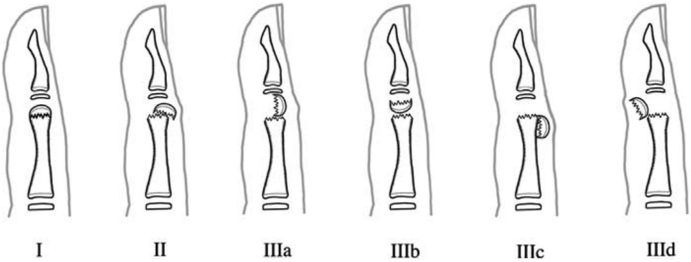

Fig. 4. Classification of phalangeal neck fractures. Type I fractures are nondisplaced. Type II fractures are displaced with some remaining cortical contact. Type III fractures are displaced with no cortical contact. (*From* Karl JW, White NJ, Strauch RJ. Percutaneous reduction and fixation of displaced phalangeal neck fractures in children. *J Pediatr Orthop*. 2012;32(2):156-161; with permission.)

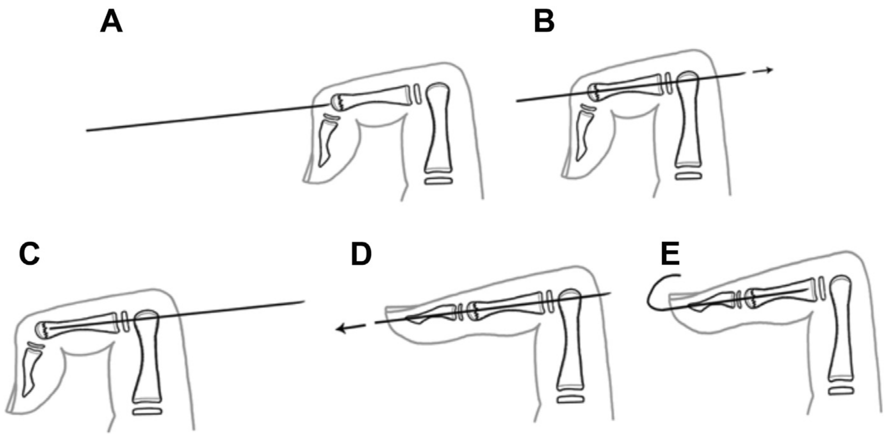

Fig. 5. Strauch pinning technique for phalangeal neck fractures. Engage the single K-wire on the reduced phalangeal head with the distal interphalangeal (DIP) joint maximally flexed (*A*). Drive the K-wire across the fracture and out skin through a flexed PIP joint (*B*). The reduction is adjusted at this time (*C*) before extending the DIP and directing the wire distally (*D*, *E*). (*From* Karl JW, White NJ, Strauch RJ. Percutaneous reduction and fixation of displaced phalangeal neck fractures in children. *J Pediatr Orthop*. 2012;32(2):156-161; with permission.)

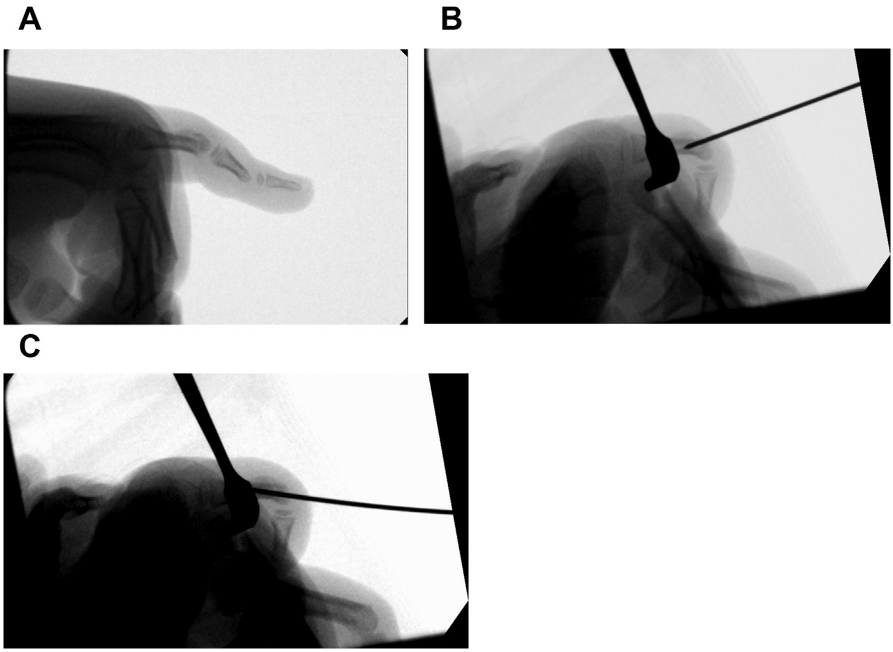

Fig. 6. Displaced phalangeal neck nascent malunion. Displaced phalangeal neck fractures that have begun to heal (*A*) are treated with osteoclasis (*B*) and pinning (*C*). (*Courtesy of* Shriners Hospital for Children Philadelphia.)

two Kirschner (K)-wires in each fragment to maintain reduction. Intercondylar fragment rotation is difficult to correct but we are willing to accept slight intercondylar malrotation provided that there is no overall malrotation of the digit and that the middle phalanx articulation is supported by the condyles and will not collapse into either varus or valgus.

Fracture of the base of the proximal phalanx, including extraoctave fractures of the small finger, is managed with closed reduction and splinting, but there is a risk of loss of reduction that is difficult to monitor with radiographs in the splint/cast. We therefore treat all complete fractures at the base of the proximal phalanx with closed reduction and pinning.

Diaphyseal fractures in the hand often present with minimal angulation, displacement, or rotational deformity. More angular deformity is tolerated in children younger than 8 years of age, with up to 30° in the fingers and 45° in the hand in the coronal plane. In older children, 20° is acceptable in the fingers and 30° in the hand. Sagittal plane deformities of more than 5° to 10° are unlikely to remodel. Shortening of up to 5 mm is also acceptable at any age. Rotational deformities are not well tolerated and do not remodel.[6–8] Phalangeal and metacarpal shaft fractures outside of acceptable parameters are best treated with closed reduction and pinning whenever possible. However, we always consent for open reduction and internal fixation, because reduction by closed means is not possible in all fractures. Care needs to be taken not to dissect through the perichondral ring or to otherwise damage or cross the physis. We use interfragmentary screws for long oblique or spiral fractures and small plates for transverse or short oblique fractures (**Fig. 7**). Metacarpal neck fractures, including boxer's fractures, are treated using the same criteria as adults, because these commonly occur near skeletal maturity. We prefer a single pin through the head and the physis and down the shaft (**Fig. 8**).

An often missed injury is the Seymour fracture, a physeal fracture of the distal phalanx (**Fig. 9**). Given that the nail plate and bed are the only barriers to the distal phalanx, any displacement of the nail plate that accompanies displacement or angulation of the distal fragment results in an open fracture. The nail bed and nail plate fragments can become interposed, leading to difficulty with reduction. Emergent irrigation and debridement is required as for any other open fracture. The nail bed needs to be tucked back under the eponychial fold. Pinning is optional, depending on stability after debridement. Delays in treatment risk malunion with permanent nail plate deformity, osteomyelitis, and in severe cases amputation. Subacute treatment includes nail plate removal, extrication of debris within the fracture, open reduction, wound culture followed by antibiotics, and stabilization of the fracture.

Thumb metacarpophalangeal joint injuries in a child usually manifest as avulsions of the ligament insertion onto the epiphysis of the proximal phalanx (**Fig. 10**). These are most commonly seen in skiers and football players. Any displacement of more than a few millimeters or rotation of the fragment can lead to long-term instability of the joint. The fragment tends to be larger than what is visible on radiographs and can make up a sizable percentage of the articular surface. We therefore opt for open reduction and fixation of the bony fragment in most cases. The approach is equivalent to the approach in adults for a metacarpophalangeal collateral ligament injury.[9] Branches of the radial sensory nerve always cross the field and can lead to a painful neuroma if overly retracted or cut. The fragment is reduced and fixed either with a K-wire, a small transepiphyseal screw (that does not cross the physis), or a suture anchor in the epiphysis. Depending on fixation, 4 to 6 weeks of postoperative immobilization is suggested.

Fig. 7. Interfragmentary screw fixation. Long oblique and spiral diaphyseal fractures are unstable injuries usually treated with interfragmentary screw fixation. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

SCAPHOID FRACTURES

The scaphoid is not fully ossified until approximately 15 years of age. It is the fifth carpal bone to begin to ossify, at between 4 and 6 years of age. The ossification center is distal, and ossification is retrograde following the blood supply. Fractures of the waist and proximal pole are therefore unlikely, and even less likely to be detected, before

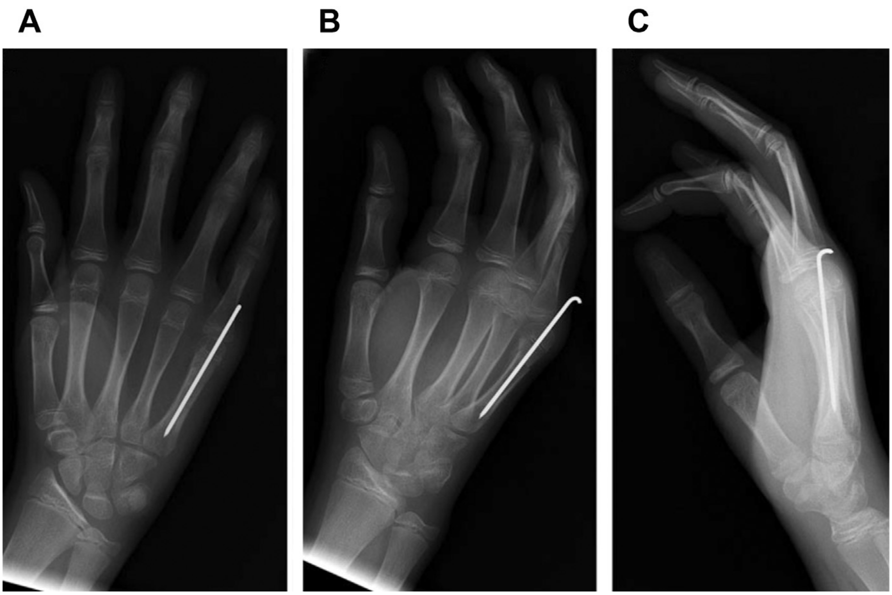

Fig. 8. Metacarpal neck fracture. Metacarpal neck fractures are stabilized with a single pin across the physis as long as there is no rotational deformity. (*A–C*) Posteroanterior, oblique, and lateral radiographs, respectively, of the pin configuration. (*From* Cassel S, Shah AS. Metacarpal Fractures. In Scott H. Kozin, Joshua Abzug, Dan A. Zlotolow, Editors. The Pediatric Upper Extremity. Springer, 2014. p. 982-1003; with permission.)

8 years of age. The so-called "bipartite" scaphoid (**Fig. 11**) has been previously described, and is a normal anatomic variant (Dormans).[10] The true atraumatic bipartite scaphoid is likely to be bilateral. A unilateral bipartite scaphoid may be the result of a cartilaginous fracture that went on to a nonunion, but this remains controversial. Regardless of congenital or traumatic cause, the bipartite scaphoid may not be a benign finding. Degenerative changes analogous to a scaphoid nonunion advanced collapse have been reported.[11]

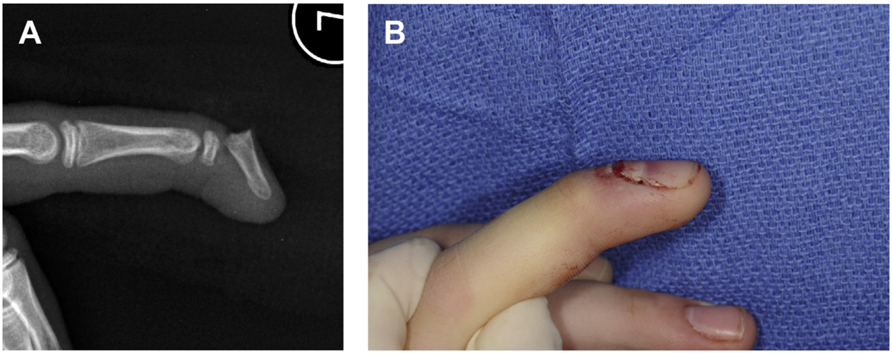

Fig. 9. Seymour fracture. The Seymour fracture is an often missed open fracture of the distal phalanx best seen on lateral radiographs (*A*). Clinical appearance can be underwhelming and contributes to the underdiagnosis (*B*). (*Courtesy of* Shriners Hospital for Children Philadelphia.)

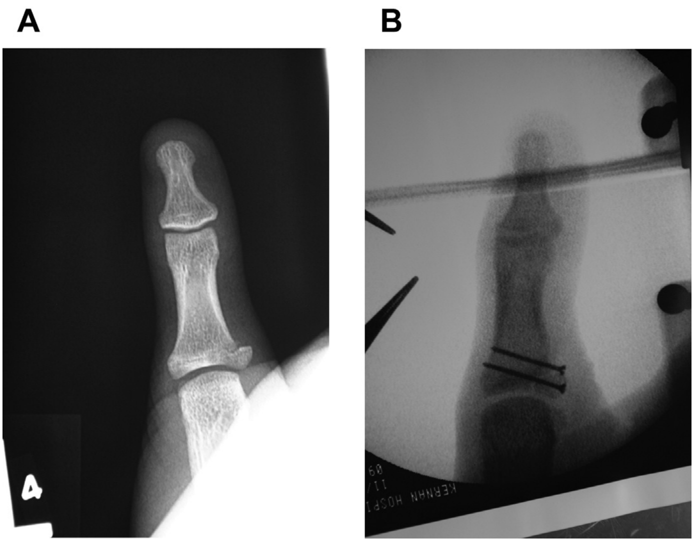

Fig. 10. Thumb metacarpophalangeal ligament avulsion. Thumb metacarpophalangeal ligament avulsion injuries are more common than ligament ruptures in children. (*A*) The fracture is usually a Salter-Harris IV injury with intra-articular involvement seen best on posteroanterior radiographs. (*B*) Treatment of displaced fractures is anatomic reduction and fixation. In this case, the physis was nearly closed, so screws traversing the physis were chosen for better fixation. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

Scaphoid fractures are still uncommon in children, making up 0.34% of pediatric fractures, but are the most common carpal fracture.[12] Up until the turn of the century, most pediatric scaphoid fractures occurred at the distal pole. The benign location of scaphoid fractures historically has created a prevailing sense among orthopedic surgeons that all scaphoid fractures in children will heal if provided a course of immobilization.[13,14] More recent studies have shown not only that fracture patterns have

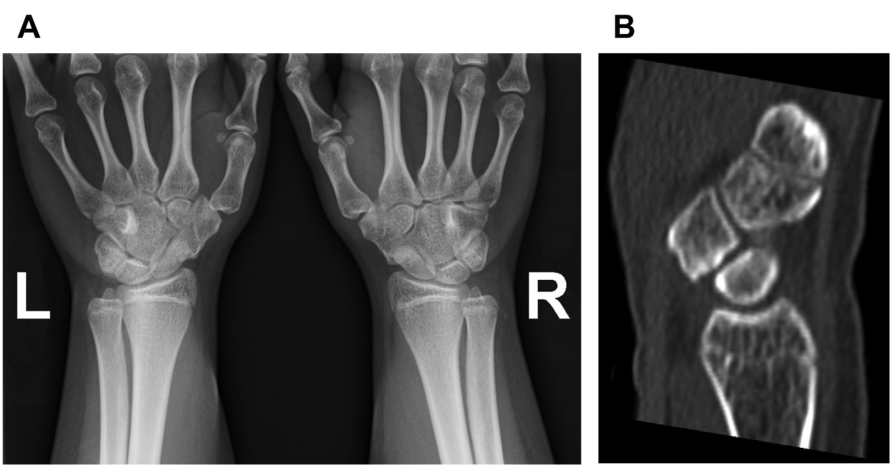

Fig. 11. Bipartite scaphoid. (*A*) Anteroposterior radiographs show bilateral bipartite scaphoids. (*B*) This is confirmed on sagittal computed tomography image. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

changed to mirror adult injuries, but that nonunion rates approach those of adults depending on status of the growth plates and the location of the fracture.[1,15–17] In children with open physes, 68% of scaphoid fractures occurred at the waist and 17% of fractures occurred at the proximal pole. Acute nondisplaced waist fractures treated in a cast had a nonunion rate of 8%.[1]

Management of scaphoid fractures is therefore similar in children as in adults, with some notable exceptions. Acute, nondisplaced fractures are treated with either cast immobilization or percutaneous screw fixation. There are no convincing data in children to indicate whether a long- or a short-arm cast is optimal, or whether thumb immobilization is required. Because of the low risk of motion loss in a child or adolescent, we tend to favor a thumb spica long-arm cast for the first 6 weeks and short-arm cast thereafter.

Percutaneous screw fixation is achieved through either a volar or a dorsal approach, provided that the scaphoid is fully ossified. If the proximal pole is cartilaginous with incomplete ossification on the radiograph, we prefer to place a retrograde volar screw (**Fig. 12**).[18] Care should be taken not to displace the fracture when placing a percutaneous screw. The screw lengths are also shorter than for adults for obvious reasons but particularly short if the scaphoid is incompletely ossified.

Displaced fractures have a high risk of nonunion, particularly if they are across the proximal pole.[1] We treat all displaced fractures with open reduction and screw fixation. Using traction, the proximal pole of the scaphoid is brought distalward, obviating division and repair of the radioscapholunate ligament (**Fig. 13**H). Preservations of

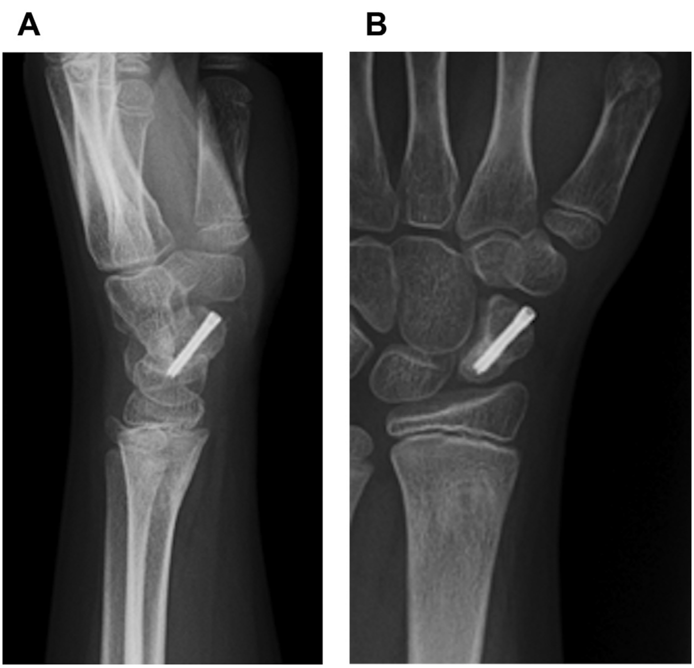

Fig. 12. Nondisplaced scaphoid fracture. Nondisplaced scaphoid fractures in children are treated with immobilization, or if the needs or wishes of the child and family require it, percutaneous screw fixation. Lateral (*A*) and posteroanterior (*B*) radiographs demonstrate a retrograde screw placed via an anterior approach because of incomplete ossification of the proximal pole in this 13-year-old boy. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

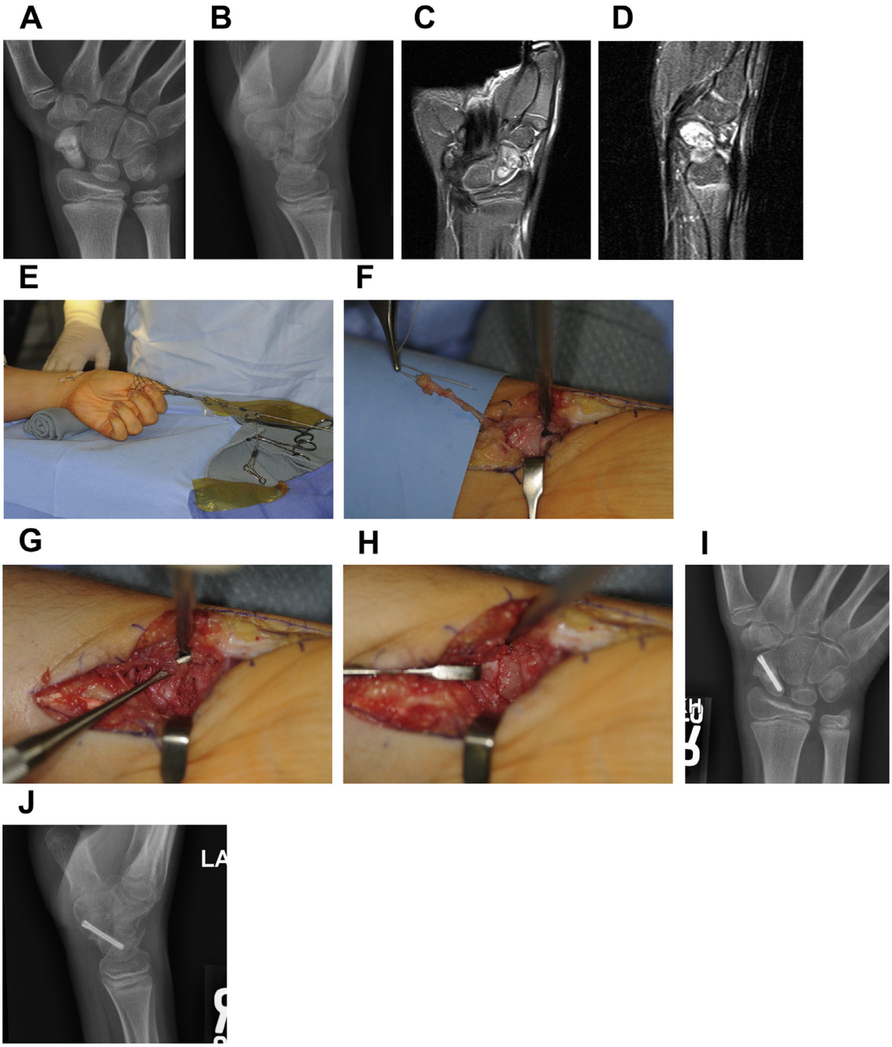

Fig. 13. Scaphoid fracture nonunion. Posteroanterior (*A*) and lateral radiographs (*B*) and coronal (*C*) and sagittal MRIs (*D*) confirmed a nonunion with a humpback deformity. The patient underwent open reduction and internal fixation using traction through the thumb using a fingertrap and a traction table (*E*). The superficial volar branch of the radial artery (*F*) was placed into the nonunion site and covered with cancellous bone graft from the distal radial metaphysis (*G*) with care not to injure the physis. A cortical fragment from the volar distal radius was then used to contain the bone graft and lend structural support to the volar scaphoid during screw compression (*H*). Six weeks later, the nonunion has healed on posteroanterior (*I*) and lateral radiographs (*J*). (*Courtesy of* Shriners Hospital for Children Philadelphia.)

carpal ligaments in children may be more important than in adults, because disruptions may change the kinematics and growth patterns of the wrist. We also routinely use a vascular pedicle from the superficial volar branch of the radial artery to inset into the fracture site.[19–21] This artery is otherwise sacrificed routinely during the approach.

Nonunions typically develop humpback deformities just as in adults (**Fig. 13**). We therefore favor a volar approach that allows correction of the deformity (https://www.youtube.com/watch?v=C43O3m6UzNM). Dorsal vascularized bone grafts that are used for adults are not an option in children, because the graft harvest site is too close or may cross the physis.[22] The volar vascularized bone graft described by Mathoulin and Haerle[23] is also not appropriate for children, because this removes the volar artery to the physis along the watershed line (**Fig. 14**). We therefore use the same vascular pedicle described previously from the superficial volar branch of the radial artery in cases of nonunion. The only published series on the vascularized pedicle technique is of four cases with a 75% union rate for nonunions with humpback deformity. The one nonunion was in a patient with a severely comminuted fracture and questionable compliance. The vascularity of the proximal pole was not defined.[20]

DISTAL RADIUS FRACTURES

Distal radius fractures are among the most common sports injuries and the most common fractures in children,[24,25] with an increasing incidence over the past 40 years.[26,27] The distal radial epiphysis does not begin to ossify until at least 6 months of age, occasionally with a secondary ossification center at the radial styloid. The distal ulnar epiphysis does not begin to ossify until at least 6 years of age. Growth from the distal radius and ulna contributes to approximately 80% of the length of the forearm. The distal ulnar physis closes typically 6 months ahead of the distal radius, at 16 years of age in girls and 17 years of age in boys.[28]

Although most are treated with closed reduction and immobilization, some undertreated injuries can result in lifelong deformity and disability. It is important to recognize and mitigate the sequelae of the “bad actors” of the pediatric wrist, while not overtreating fractures that will remodel. Angulation in the plane of motion of the wrist can remodel at an average rate of 10° per year of growth remaining.[29]

True buckle, or torus, fractures with minimal angulation are treated in a splint or a cast for 3 weeks.[30] A true buckle fracture has anterior and posterior cortices intact, with a slight buckling on one cortex and a nearly imperceptible plastic deformation of the other side. Salter-Harris II fractures can look like buckle fractures if nondisplaced, but there is usually a fracture line to the physis or a slight misalignment of the epiphysis and the metaphysis. These occult Salter-Harris II fractures can displace,

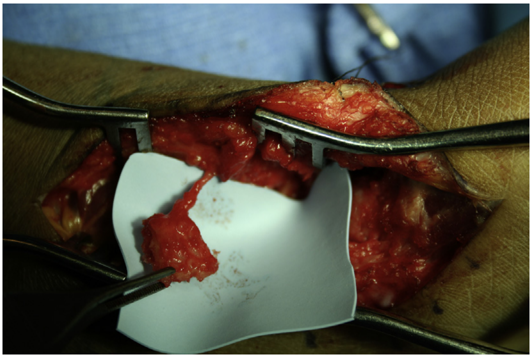

Fig. 14. Volar vascularized bone graft. Intraoperative photograph showing the volar vascularized bone graft described by Mathoulin and Haerle.[23] Note that the pedicle is the volar blood supply to the physis and the bone is adjacent to the physis, and therefore cannot be used in skeletally immature children. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

so a well-molded plaster short-arm cast and close observation with weekly radiographs is recommended.

More displaced Salter-Harris type II fractures generally require a reduction. The best scenario is a timely closed reduction and either plaster sugar-tong splint or long-arm cast on the day of injury. However, because many emergency departments are not able to provide this service, patients typically present with still displaced fractures in a tightly bandaged poorly made splint[31] many days after injury. Initial evaluation includes orthogonal radiographs before splint removal to evaluate for any further displacement. If the splint is adequate, retain the splint. If not, the splint has to be changed. Before splint removal, we prefer to place the child in linear traction via the thumb only with the elbow bent 90° and 5 lb of weight on the brachium, which is parallel to the floor (**Fig. 15**).[18,32] Traction reduces the risk of further fracture displacement and minimizes the number of assistants required for the splint change.

If the Salter-Harris II fracture is less than 7 days old, we take the child to the operating room for a closed reduction and casting (**Fig. 16**). Fractures older than 7 days old are best left unreduced. It is better to have a deformity than a physeal arrest. Large Thurston-Holland fragments render fractures unstable and usually require percutaneous pinning for stability. Fractures with smaller metaphyseal fragments are usually

Fig. 15. Traction for distal radius fracture. Both a cast or splint change and a closed reduction are most easily achieved using elbow flexion and traction across only the thumb to neutralize the primary deforming force of the brachioradialis. (*Courtesy of* Steven J. Thompson and Dan A. Zlotolow.)

Fig. 16. Salter-Harris II fracture with small Thurston-Holland fragment. Posteroanterior (*A*) and lateral (*B*) radiographs demonstrate a displaced Salter-Harris II fracture of the distal radius with a small Thurston-Holland fragment. These injuries typically are treated with a closed reduction and casting in a well-molded plaster long-arm cast (*C*, *D*). Note that the plaster has no visible onion-skinning (layering) and that the mold is deep and in the appropriate location. The padding is minimal and the cast index is less than 0.7. Posteroanterior (*E*) and lateral (*F*) radiographs 4 weeks later confirmed union and the patient was nontender at the fracture site. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

stable and rarely require fixation. However, every fracture must be assessed individually for stability. Long-arm, well-molded plaster casts are preferred if no fixation is used because there is no opportunity for rereduction. Follow-up is 1 week later with radiographs. If there is any redisplacement, the incidence of physeal arrest is too great to attempt a rereduction in most cases. Salter-Harris III and IV fractures are intra-articular and require a reduction even at the risk of physeal arrest. Type III fractures develop a bar if not anatomically reduced. Type IV fractures also have a high risk of growth arrest, regardless of reduction. Physeal injuries of the distal radius carry a 5% risk of growth arrest. By contrast, ulnar physeal injuries carry a 50% risk.

Extra-articular, extraphyseal fractures in the metaphysis are unlikely to go on to physeal arrest, but associated ligamentous and/or distal ulnar fractures can lead to long-term instability. It is difficult to define an acceptable reduction, because so many factors play a role, including the risk of loss of reduction. A quarter of all complete metaphyseal fractures in children redisplace after closed reduction and immobilization. The risk is greater if initial angulation was greater than 30° in the sagittal plane or the fracture was more than 50% displaced.[33–35] Associated ulnar fractures increase the risk of redisplacement. We therefore attempt a closed reduction and cast/splint in children younger than 10 years of age regardless of initial angulation if there is no ulnar fracture and there is minimal displacement, so long as the fracture does not have a long oblique orientation. Given that these long oblique shear fractures are inherently unstable, we rigidly fix any displaced fracture that has a shear component (**Fig. 17**). Transverse metaphyseal fractures are stable once reduced and merit at least an attempt at closed management. Risk factors for redisplacement of metaphyseal fractures include greater than 50% initial translation and poor cast technique. We recommend minimal padding, plaster sugar-tong splint or below the elbow cast with a good mold, and a cast index of less than 0.7.[18,32] Despite evidence of the success of short-arm cast, we do not hesitate to place a long-arm cast if rotational stability is in question. In children younger than 5, a long-arm cast with the elbow at 90° is usually required to keep the cast on.

If there is evidence of distal radioulnar ligamentous injury, such as initial or persistent distal radioulnar joint (DRUJ) subluxation on radiographs, a large ulnar styloid fracture fragment, or intraoperative instability of the DRUJ, we advocate for rigid fixation and anatomic reduction. Although most metaphyseal fractures are not true Galeazzi injuries,[36] a high index of suspicion should be maintained.

Follow-up for metaphyseal fractures treated with closed reduction without fixation should be reimaged weekly to assess reduction. Rereduction in the operating room is recommended if angulation exceeds 20° of dorsal tilt or 10° loss of inclination in children with more than 2 years of growth remaining. Less angulation is tolerated in older children and adolescents.

GYMNAST WRIST

Humans are the only primate to walk on their hands, and we only do it regularly as gymnasts. Our closest relatives, the other great apes, walk on their forelimbs but weight bear either across their middle phalanges or proximal phalanges, with the wrist in neutral. They rarely place all of their weight on a single forelimb. High-level gymnasts are expected not only to repeatedly walk on their hands, but also to bear loads at multiples of body weight on a daily basis, and to do so on the palm of the hand with the wrist in terminal extension. This highly nonphysiologic loading pattern causes concentration of supraphysiologic load across the wrist. Because this type of weight bearing begins at a young age in girls, and particularly because puberty is delayed in this demographic, the physis of the distal radius responds with hypertrophy, edema, and eventually arrest.

Wrist pain in a gymnast, particularly a young girl, should merit at least radiographs of the wrist regardless of the examination (**Fig. 18**). Contralateral comparison film may be necessary. Any widening of the physis on radiograph requires cessation of gymnastics training and splinting or, if severe, immobilization in a cast until the pain resolves. The athlete may return to gymnastics once the radiographs normalize, the patient is pain free, and there is no tenderness about the distal radius. The timing can vary greatly but 6 weeks is minimal.

Longstanding or severe physiolysis can lead to complete or, more commonly, partial physeal arrest (**Figs. 19** and **20**). This is difficult to manage in the young girl who still

Fig. 17. Salter-Harris II fracture with large oblique Thurston-Holland fragment. Posteroanterior (*A*) and lateral (*B*) radiographs demonstrate a displaced Salter-Harris II fracture of the distal radius with a large oblique Thurston-Holland fragment. These fractures are inherently unstable and require buttress plating. Posteroanterior (*C*) and lateral (*D*) radiographs 6 weeks later confirmed union and the patient was nontender at the fracture site. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

has many years of growth remaining. Girls generally reach skeletal maturity 2 years after menarche, usually around 14 years of age. Boys reach skeletal maturity around 16 years of age. Partial growth arrest of the distal radius results in angular deformity and ulnar-positive variance. Bowing of the radial and ulnar diaphyses is common.

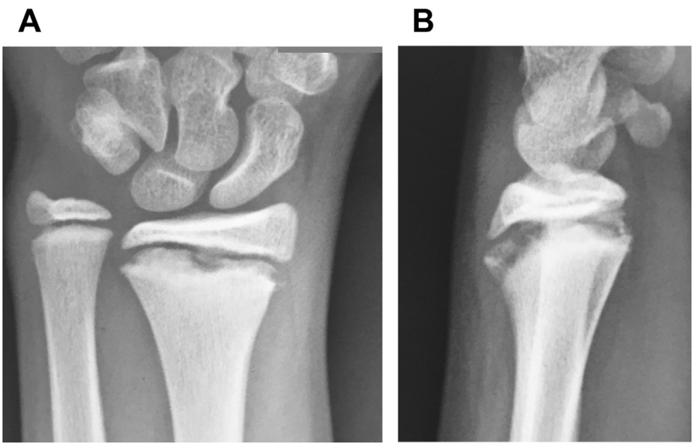

Fig. 18. Gymnast wrist. Posteroanterior (*A*) and lateral (*B*) radiographs of a gymnast with wrist pain demonstrate widening of the physis with irregular calcification. There is already evidence of radial growth arrest or slowing with a markedly ulnar-positive variance. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

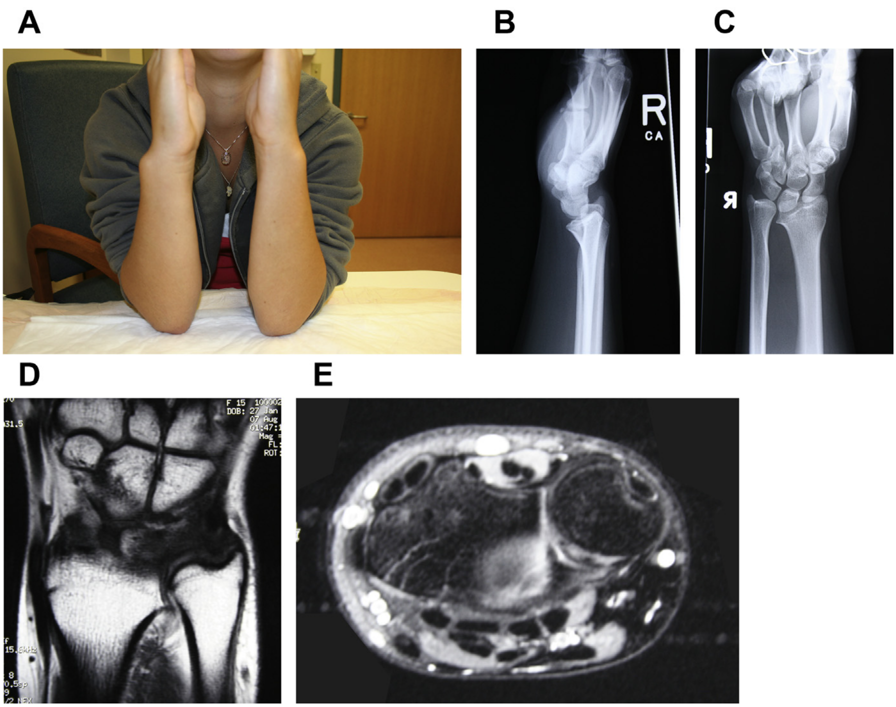

Fig. 19. Chronic gymnast wrist with physeal arrest. A 16-year-old female gymnast presented with wrist deformity (*A*) and pain. Radiographs showed a "Madelung" type deformity with growth arrest of the distal radial volar/ulnar corner in a skeletally mature wrist (*B*, *C*). MRI did not show a Vicker ligament (*D*, *E*), consistent with her history. The absence of a Vicker ligament confirms that her etiology was not a true Madelung case, but rather most likely the result of repetitive trauma or acute injury to the physis. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

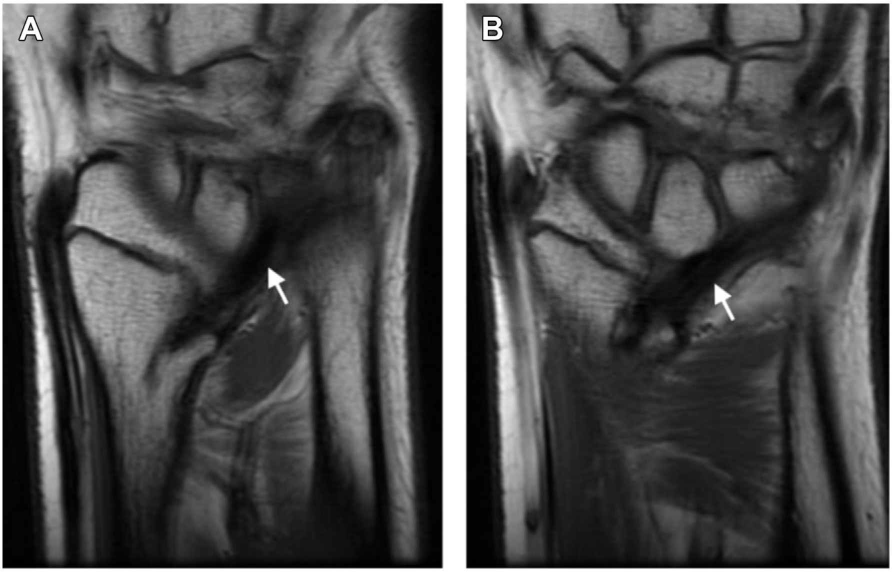

Fig. 20. (*A* and *B*) demonstrate sequential coronal T1 weighted MRI images of the wrist in a patient with Leri-Weill Dischondrosteosis with a clearly visible Vicker's ligament (*white arrows*).

An MRI is used to determine the percentage of remaining open physis. Anything less than 70% of the physis remaining is highly unlikely to respond to bar resection. In our experience, even if 85% of the physis remains open by MRI criteria, physeal bar resection may recover a year or 2 of growth but eventually the physis closes prematurely and radioulnar growth discrepancy remains.

Complete growth arrest leads to early ulnar-positive variance and late ulnar bowing if the ulna is allowed to grow while the radius does not. Caught early, before positive ulnar variance is noted, and in a child near skeletal maturity, an ulnar epiphyseodesis is performed to prevent length discrepancy between the radius and the ulna. We prefer to use a small 2-cm transverse incision over the subcutaneous border of the ulna at the level of the physis. Blunt dissection is performed down to the capsule to identify and protect the dorsal sensory branch of the ulnar nerve. A guidewire is inserted into the physis under fluoroscopic guidance and a 1.7-mm cannulated drill is used to enter the physis (**Fig. 21**). We then use a small curette to remove the physeal cartilage without further violating the perichondral ring. Fixation is not required. A short arm splint is used for 2 weeks and the child is allowed to return to sports when bridging bone is seen, typically 6 weeks after surgery.

Young patients with an arrest that is picked up before radioulnar length discrepancy becomes symptomatic are difficult to manage. The patient and the family need to decide between two treatment strategies: serial radial lengthenings with an external fixator to keep up with a growing ulna performed approximately every 2 years until skeletal maturity; or ulnar epiphyseodesis with the acceptance of a potentially very short forearm at skeletal maturity. This is a difficult decision, and both likely result in cessation of athletic competition.

Radial lengthening is more complicated to perform than ulnar lengthening, because there is no subcutaneous border of the radius. We prefer a Thompson approach[37] to the midshaft radius with use of a monoplanar external fixator (**Fig. 22**). In two case

Fig. 21. Epiphyseodesis. Epiphyseodesis is performed with a 1.7-mm cannulated drill (shown) and expanded with a curette. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

series of four patients each, radial lengthening showed good clinical outcomes with a postoperative DASH score of 11 and 2 and a Mayo wrist score of 76 and 89. Length of distraction was not reported in either study. A circular frame was used in both studies for a total of 106 and 150 days, respectively.[38,39]

Patients who present late or are underdiagnosed initially that already have a radio-ulnar length discrepancy require either a radial lengthening, ulnar shortening, or both. Again the decision to either undergo potentially multiple complex operations or to live with a short forearm is highly personal and has long-term consequences. Correction of any ulnar deformity, when present, is performed at the same time with a closing wedge osteotomy. For complex deformities, computed tomography–based computer modeling may be used.

If the radiographs are normal, a period of 2 weeks of immobilization in a cast or splint is recommended. If the pain is resolved, gradual return to full activities is permitted. If

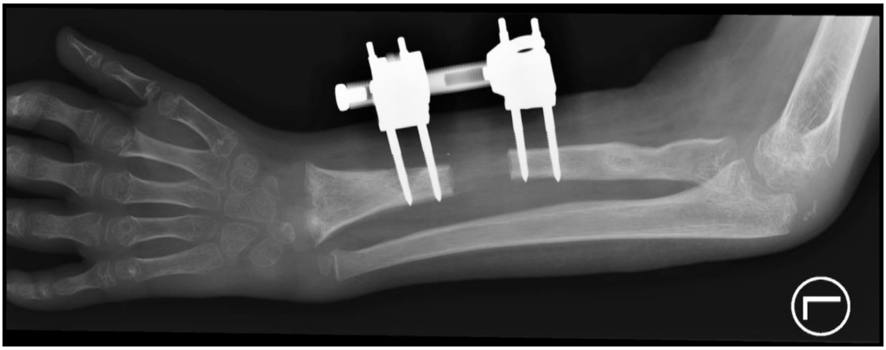

Fig. 22. Radial lengthening. The radius is lengthened with a monoplanar external fixator via the Thompson approach. (*Courtesy of* Shriners Hospital for Children Philadelphia.)

the pain continues, MRI examination of the wrist may be necessary. Early changes in the physis are seen on MRI, and occult fractures, stress fractures, carpal avascular necrosis, ulnocarpal impaction, TFCC tears, and redundancy of the dorsal capsule with synovitis.

ULNAR-SIDED WRIST PAIN

Injuries to the TFCC of the wrist can occur in the setting of distal radial and/or ulnar fractures or in isolation.[40,41] It is rare for a child to develop longstanding DRUJ instability from a TFCC tear unless there is an associated malunion of the forearm or wrist. However, true DRUJ instability can lead to pain, disability, and potentially erosion of the growing sigmoid notch. Children may also develop ulnocarpal impaction as a result of radial growth arrest/delay or ulnar overgrowth.

Traumatic TFCC injuries with associated wrist fractures are uncommon[36] and typically heal if the bony anatomy is restored. Patients may present many years after injury with a history of fracture but no evidence of a fracture or a malunion on radiographs. In these patients, remodeling will have erased the evidence, but the sequelae of the fracture malunion remain with malalignment of the DRUJ. In these patients, it is important to assess the injury and immediate postunion films to determine the degree of malunion. MRI has been shown to have a 50% false-negative rate for diagnosing a TFCC tear in children.[41] In our practice, we perform diagnostic/therapeutic steroid injections after rest, splinting, and activity modification have failed to relieve symptoms. If the pain improves immediately after injection of the TFCC but recurs, an arthroscopy is recommended.

Oftentimes, restoration of the bony alignment without a soft-tissue procedure is sufficient to stabilize the DRUJ.[42] Patients with persistent DRUJ instability after a fracture are difficult to treat because even a small degree of malunion, which is often the case with any initially displaced or angulated pediatric wrist fracture not treated with an open reduction, can lead to symptomatic DRUJ microinstability and subtle but clinically significant sigmoid notch dysplasia. We agree with Miller and colleagues[42] that restoration of bony anatomy is necessary and sufficient for stabilization of the DRUJ in children. Likewise, in the absence of a fracture, DRUJ instability is rare. There may be a history of trauma leading to an undiagnosed fracture or plastic deformation.

The typical adult DRUJ ligament reconstruction using volar and dorsal constructs passed through the ulnar head[43] is not possible in children because it crosses the distal ulnar physis. We have performed delayed TFCC repairs in adolescents after restoration of bony anatomy did not stabilize the DRUJ, with good results in a limited number of patients. Most tears are Palmer 1B. Both open and arthroscopic repair techniques have yielded good results. Out of 22 open repairs, all but 7 had complete resolution of their symptoms.[41] In another series of 12 patients with an average of 16 years, patients treated with an arthroscopically assisted TFCC repair for Palmer 1B tears decreased their pain score from an average of 7 to less than 2, and had a DASH of 16 at final follow-up.[44] If a repair is not possible or fails, delayed ligament reconstruction after skeletal maturity is recommended.

Another common source of ulnar-sided wrist pain in athletes is ulnocarpal or stylocarpal impaction. Most commonly there is a history of a wrist injury that likely resulted in either a growth disruption of the distal radius or an overgrowth of the ulna. However, idiopathic ulnar-positive variance can occur. Contralateral true posteroanterior radiographs in idiopathic cases often reveal identical variance on the symptomatic and nonsymptomatic sides, raising the question of why only one side hurts.

Regardless of cause, restoring a neutral to slightly negative variance has worked well in our practice. There is currently no study on ulnar shortening in children, with or without arthroscopic TFCC debridement, so the optimal treatment remains controversial. In skeletally immature patients who are near the end of growth but have open physes at the radius and the ulna, epiphyseodesis of the ulna is considered, allowing the radius to grow longer than the ulna. Regular interval follow-ups with radiographs every 4 to 6 months are required to ensure that the radius does not overgrow. If the radius reaches the desired length but growth remains, an epiphyseodesis is performed.

In younger patients, it may be best to wait and observe with interval follow-up again every 4 to 6 months. The variance may self-correct with time, and ulnar epiphyseodesis in a young child's arm leads to a tethering of the distal radius and potentially risks excessive radial inclination and bowing, and radial head dislocation. The forearm also remains short. If the radius and ulna seem to be growing at the same rate and the variance has not changed after a year, consider ulnar shortening without an epiphyseodesis and continue to observe the patient until skeletal maturity. Overcorrection of the variance by a few millimeters may be performed, because the osteotomy may lead to acceleration of growth at the ulna.

SUMMARY

The hand and wrist of the pediatric athlete merit special considerations for the remodeling potential of fractures and the long-term sequelae of malunited fractures, growth arrest, early joint degeneration, and ligamentous instability. The success of remodeling cannot be overestimated, because not all fractures remodel. However, the tolerance for malunion must be higher in children with growth remaining than in adults, unless joint instability, articular incongruity, or physeal malalignment are at risk.

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