Operative Techniques in
Orthopaedics

What is New in Pediatric Wrist Fractures?

Greg Grenier, DO, and Julie Balch Samora, MD, PhD

There are a multitude of unique issues that arise in the management of wrist injuries in the pediatric population. The pediatric wrist is a complex region that is susceptible to both acute and chronic injuries. A thorough understanding of the unique anatomy and radiographic progression of ossification of the pediatric wrist is necessary for both diagnoses and treatment. This review will cover the most recent literature regarding the management of distal radius fractures and scaphoid fractures in the pediatric patient population.
Oper Tech Orthop 29:55-66

KEYWORDS pediatric wrist fractures, distal radius fractures, scaphoid fractures, conservative management, surgical management

Introduction

The pediatric wrist is a complex region that is susceptible to both acute and chronic injuries. There are a multitude of unique issues that arise in the management of wrist injuries in the pediatric population. A thorough understanding of the unique anatomy and radiographic progression of ossification of the pediatric wrist is necessary for both diagnoses and treatment. Although pediatric patients usually do well after properly treated wrist injuries, complications from missed diagnoses and inappropriate treatment can lead to significant complications and limitations in functional outcomes. This review will cover the most recent literature regarding the management of wrist injuries in the pediatric patient.

Distal Radius Fractures

Distal radius fractures account for 20%-31% of all pediatric fractures.[1-6] With an increase in body mass index, a decrease in bone mineral density, and an increase in the participation in more intense, higher energy sporting activities, the annual incidence of distal radius fractures is increasing.[7-9] It is estimated that 1 in 100 children will sustain a distal radius fracture.[5,10,11] Recent data have demonstrated the highest incidence of fractures occurring in females 8-11 years and males 11-14 years.[9] Pediatric patients are most at risk with the onset of puberty, when skeletal growth occurs without a significant concomitant increase in bone mineral density. This mismatch leads to increased bone fragility and places these children at a higher risk of fracture.[1,12,13] Leonard et al demonstrated a 0.45 increase in radius cortical section modulus Z-score in obese children compared to nonobese children,[14] thus potentially indicating a protective mechanism from fractures due to obesity. However, others have shown that obese children have suboptimal bone quality, thus imparting an increased risk for complex extremity fractures.[15-22] There is no current consensus on the role that obesity plays in pediatric distal radius fractures. We do know that there is an increased prevalence of Vitamin D insufficiency or deficiency in pediatric patients that sustain a distal radius impaction type injury compared to patients without insufficiency.[23]

Pathoanatomy

An understanding of the anatomy and radiographic appearance of the distal radius will allow clinicians to properly identify and manage injuries. The physis is biomechanically weaker than the surrounding mature bone and ligamentous structures, which accounts for the greater proportion of fractures occurring in and around the physis. The distal radius epiphysis appears in males aged 0.5-2.3 years and females 0.4-1.7 years,[24] with the distal ulna epiphysis appearing around 7 years. Closure of the physis occurs around

Nationwide Children's Hospital, Columbus, OH.
Funding: No research support.
Conflicts of interest: No conflicts of interest.
Address reprint requests to Julie Balch Samora, MD, PhD, Nationwide Children's Hospital, 700 Children's Drive T2E-A2700, Columbus, OH 43205. E-mail: julie.samora@nationwidechildrens.org

https://doi.org/10.1053/j.oto.2018.12.010
1048-6666/

17.5 years in males and 16.6 years in females.[24] With 75% of longitudinal growth of the radius occurring at the distal physis, there is marked potential for distal radius remodeling to occur after injury.[25] Bae et al demonstrated that up to 10° of palmar-dorsal angulation remodeling potential can occur per year.[26] Fung et al[27] reported that there is rapid remineralization in adolescents who sustain a distal radius fracture secondary to a transient elevation of bone mineral density.

Clarifying between extra-physeal and physeal injuries is of utmost importance, with physeal fractures subclassified using the Salter-Harris classification. Metaphyseal involvement is most common in extraphyseal fractures. Recognizing the amount of cortical involvement aids in understanding of the inherent stability of the fracture. Buckle fractures most commonly occur after a mechanical compressive force and only involve 1 cortex with an intact periosteum. These fractures are inherently stable. Complete distal radius fractures have involvement of both cortices and are inherently unstable.

Imaging

The Amsterdam pediatric wrist rules established in 2015 demonstrate a sensitivity of 95.9% and specificity of 37.3%. They recommend obtaining radiographs when a pediatric patient presents with swelling and/or visible deformity of the distal radius, pain upon palpation of the anatomic snuffbox and pain with supination. They demonstrated a 22% reduction in the amount of radiographs ordered in the emergency department.

The use of ultrasound to diagnose distal radius injuries has received increased attention recently. Douma-den Hamer et al in 2016[23] published a systematic review and diagnostic meta-analysis demonstrating a sensitivity of 97%, specificity of 95%, positive likelihood ratio of 20.0, and negative likelihood ration of 0.03 when ultrasound was used to detect distal radius fractures. In addition, Ko et al[28] published the results of their Pediatric Distal Radius Ultrasound Study. They demonstrated that in patients aged 2-15 years who present with distal forearm injuries without deformity, bedside ultrasonography had a sensitivity of 97.1%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 94.1% in detecting distal radius fractures. The utilization of ultrasound in diagnosing distal radius fractures needs to be weighed against its ability to determine correct treatment based upon the fracture pattern. Hedelin et al[29] stated that while ultrasound in novice hands is comparable to radiographs in identifying distal radius fractures, it did misclassify 7/116 fractures as incomplete when in fact they were complete fractures on radiographs, thus potentially placing those 7 patients at risk for inappropriate treatment.

Treatment

The guiding principle in the treatment of distal radius fractures is dependent on age, location, and the amount of displacement. While there are continued discussions regarding acceptable angles for distal radius fractures, there is no new evidence on amount of acceptable tolerances in the past 5 years.

While the gold standard for treatment of distal radius buckle fractures has historically been to utilize cast for 2-4 weeks with return to the office for cast removal, evaluation, and repeat radiographs,[30-32] there have been multiple recent randomized controlled trials that have demonstrated similar outcomes with noncast treatment (ie, prefabricated/removable splints, sugar tong splints).[33-36] Kuba et al[37] demonstrated nearly universal good patient outcomes and parental satisfaction in 43 patients with distal radius buckle fractures treated with removable wrist braces and no additional clinical or radiological follow-up. Ling et al[38] showed a potential cost savings of $55,890 per year by not performing serial radiographs in pediatric patients who present with distal radius buckle fractures. Despite these data, studies by Bernthal[39] and Dua[40] demonstrated that only 29.1% of pediatric orthopaedic surgeons utilize removable wrist splints in the treatment of buckle fractures. At our institution, we provide Velcro braces for all distal radius buckle fractures and do not require the patients to return for follow-up evaluation or radiographs (Fig. 1)[117].

Greenstick fractures are less stable that buckle fractures and do often require formal reduction and an appropriately molded form of immobilization. These injuries require vigilance with clinical and radiographic follow-up. Several studies[41-43] have demonstrated no differences in complication rates or loss of reductions in patients who underwent immobilization after reduction for greenstick fractures with either short arm, long arm, or prefabricated splints. Boyer et al[44] showed that forearm position (pronation, neutral, and supination) during immobilization failed to show a significant effect on fracture angulation at union. Ting et al[45] performed a retrospective study of 109 patients who underwent closed reduction and long arm cast immobilization for greenstick distal radius fractures and found that 2 clinical follow-up visits and 3 sets of radiographs would reduce overall care costs by 14.3% and radiation exposure by 41% without compromising overall clinical results. They noted 94% of patients met criteria for acceptable alignment with 1 patient having to undergo rereduction.

Fractures that present with significant displacement, shortening, or malrotation and those that are displaced beyond what could be considered to undergo acceptable remodeling should undergo formal closed reduction and stabilization. The forms of stabilization should proceed from splint or casting to percutaneous pinning to open reduction and internal fixation (ORIF), based upon the age, integrity of the soft tissues, fracture properties, associated injuries, and overall health of the patient.[40]

When closed reduction and splint or cast immobilization in the emergency room are attempted, there are multiple options available for sedation and/or local/regional anesthetic. Bear[46] showed that the utilization of a hematoma block for reduction of distal radius fractures had comparable results in relation to radiographic alignment, patient satisfaction, and pain control while also demonstrating significantly decreased emergency department time and resources when

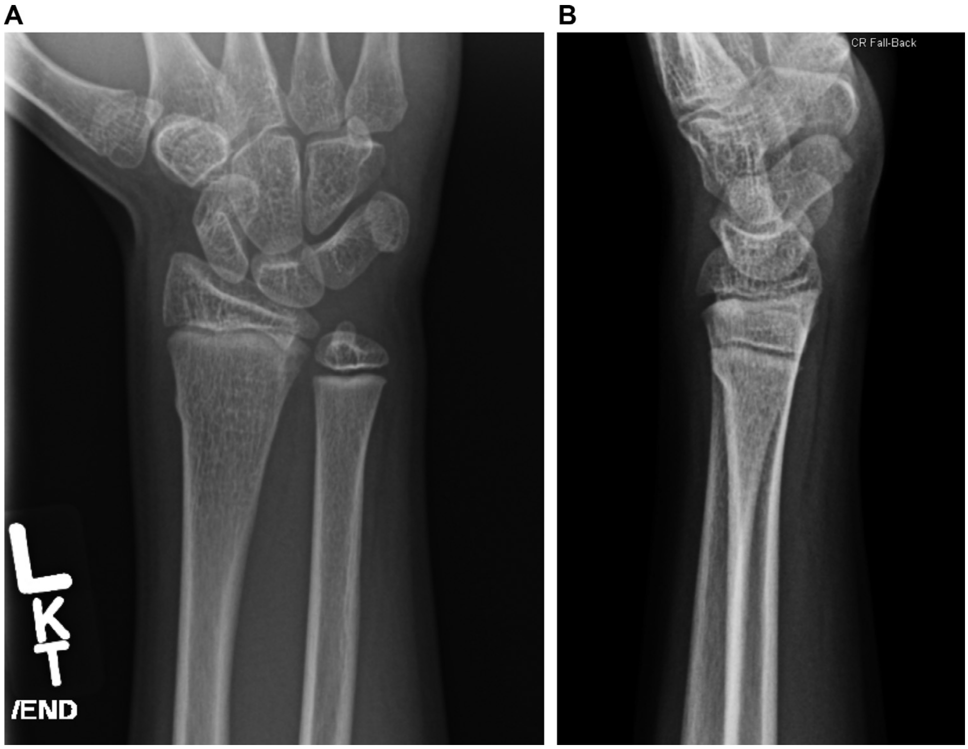

Figure 1 AP (A) and lateral (B) radiographs depicting a stable distal radius buckle fracture. On AP imaging, there is a "buckling" of the metaphyseal cortex. On the lateral image, there are 2 points of inflection. This patient would receive a Velcro brace at our institution, without formal follow-up.

compared to procedural sedation. In a randomized controlled trial comparing the use of nitrous oxide plus hematoma block vs ketamine and midazolam, Luhmann et al[47] demonstrated fewer adverse effects, significantly decreased recovery time, and decreased patient and parent-reported procedural distress and pain with the nitrous oxide/ketamine regime. Tseng[48] completed a meta-analysis of 4 randomized controlled studies and 1 nonrandomized study, including 2 on pediatric patients comparing hematoma blocks vs procedural sedation for the reduction of distal radius fractures. They found that hematoma blocks are safe and effective, without providing inferior pain relief compared to procedural sedation.

Utilization of a 3-point mold with a cast index of less than 0.8 has been shown to significantly decrease the risk of redisplacement.[49] Additional studies have demonstrated not only good intrarater and interrater reliability of cast index measurements, but also the significant radiographic measurement of cast index to predict redisplacement of fractures in children.[50,51] When debating between short vs long arm casting, both Bohm[42] and Webb[43] demonstrated that well-molded short arm casts are as effective in maintaining reduction of fractures compared to well-molded long arm casts, so long as the cast index was good. Abson[52] compared residents to attending surgeons and found that seniority did not influence the cast index or redisplacement/angulation of fractures after closed reduction.

Utilization of the mini c-arm in the emergency department for assistance in the closed reduction of distal radius fractures has brought about concerns for radiation exposure. Sumko[53] looked at the amount of radiation exposure present with the use of the mini c-arm and found that the average millirem (mR) for distal radius fractures was 63 mR, compared to conventional radiography (PA/lateral) of the distal radius of 20 mR. He stated that the amount of radiation exposure had been underestimated with the use of the mini c-arm and advocated for residents to undergo specific training. The implementation of a specific training program for residents comparing the amount of radiation and mini c-arm exposure time to residents and patients before and after the training demonstrated a decreased amount of radiation exposure and mini c-arm exposure time after the training.[54] Gendelberg et al[55] then looked at the efficacy of their mini c-arm training 11 months after the initial training and compared it to residents without any training and residents who just completed the training. He found that while there was no significant difference in radiation exposure between residents who completed the training 11 months prior and those who just completed the training, there was a significant difference in radiation exposure between the residents who completed the training 11 months prior and those who did not complete the training.

Clinical and radiographic follow-up after reduction and casting of distal radius fractures has historically been recommended for the first 2-3 weeks to evaluate for redisplacement.[10] However, Luther[56] found that there was minimal change in the position of distal radius fractures 2 weeks after closed reduction and immobilization, and radiographs at 4 weeks had minimal influence on clinical decision making, while its elimination would potentially save 11.9% in the overall cost of nonoperative treatment. The use of Gore-Tex lined casts allows the child to participate in water-based activities and can be helpful in maintaining hygiene over the course of treatment. However, there has been concern over the ability of Gore-Tex to maintain reduction of distal radius fractures compared to cotton padding. Robert[57] compared Gore-Tex lined casts to traditional cotton lined casts in maintaining reduction of distal radius fractures with an initial 100% displacement. He found that both casts were equally effective in maintaining reduction with no significant differences in final AP and lateral radiographs. It is important to recognize the factors that could potentially lead to redisplacement inpatients. Luther[56] in his prospective study of 143 patients found that initial radius displacement >75%, concomitant ulna fracture, and dominant arm involvement were all independent risk factors for loss of reduction. Auer[58] found that obesity in childhood leads to high rates of malreductions and subsequent manipulations following closed reduction and casting of distal radius fractures.

When a previously reduced and immobilized distal radius fracture loses reduction in the cast, there are several options available for the treating surgeon. Cast wedging has been utilized to help treat developing malalignment in distal radius fractures treated with cast immobilization. Samora et al[59] demonstrated significant improvement in angulation of both bone forearm fractures from prewedge to final films in 69 or 70 patients treated with cast wedging in clinic without the use of anesthesia. In a systematic review of 3 studies encompassing 258/316 patients who sustained forearm fractures and underwent cast wedging, Gaukel[60] found cast wedging to be a safe and reliable treatment option for secondary displacement of pediatric long bone fractures. We will often utilize cast wedging (Fig. 2), but if the cast index is not within reason, it is unlikely to be successful.

Closed reduction percutaneous pinning (CRPP) and ORIF for distal radius fractures are the options available for surgeons when faced with irreducible fractures, open fractures, displaced intra-articular fractures, fractures with unacceptable alignment after attempted closed reduction, loss of reduction, and floating elbow injuries (Fig. 3). Percutaneous pinning after closed reduction has excellent results and avoids some of the risks associated with ORIF. Khandekar[61] completed a systematic review of 64 studies with 527 patients who sustained a distal radius fracture treated with Kirchner wires. The most common indications for utilization of k-wires were completely displaced fractures and those translated more than 50%. The most common technique involved retrograde placement of 2 cross wires in non-Kapandji fashion with the wires ends out of the skin. The majority of patients were placed into long arm casts, although they were not found to be superior compared to short arm casts in time to fracture healing or redisplacement rate. Wires were removed at 3-6 weeks with the majority being removed at 3-4 weeks after surgery. Complication rates ranged from 0% to 38% (median 8.3%) with all being classified as minor and no long-term disabilities resulted secondary to the complications. Parikh[62] reported on 10 patients who underwent intrafocal pinning technique for distal radius

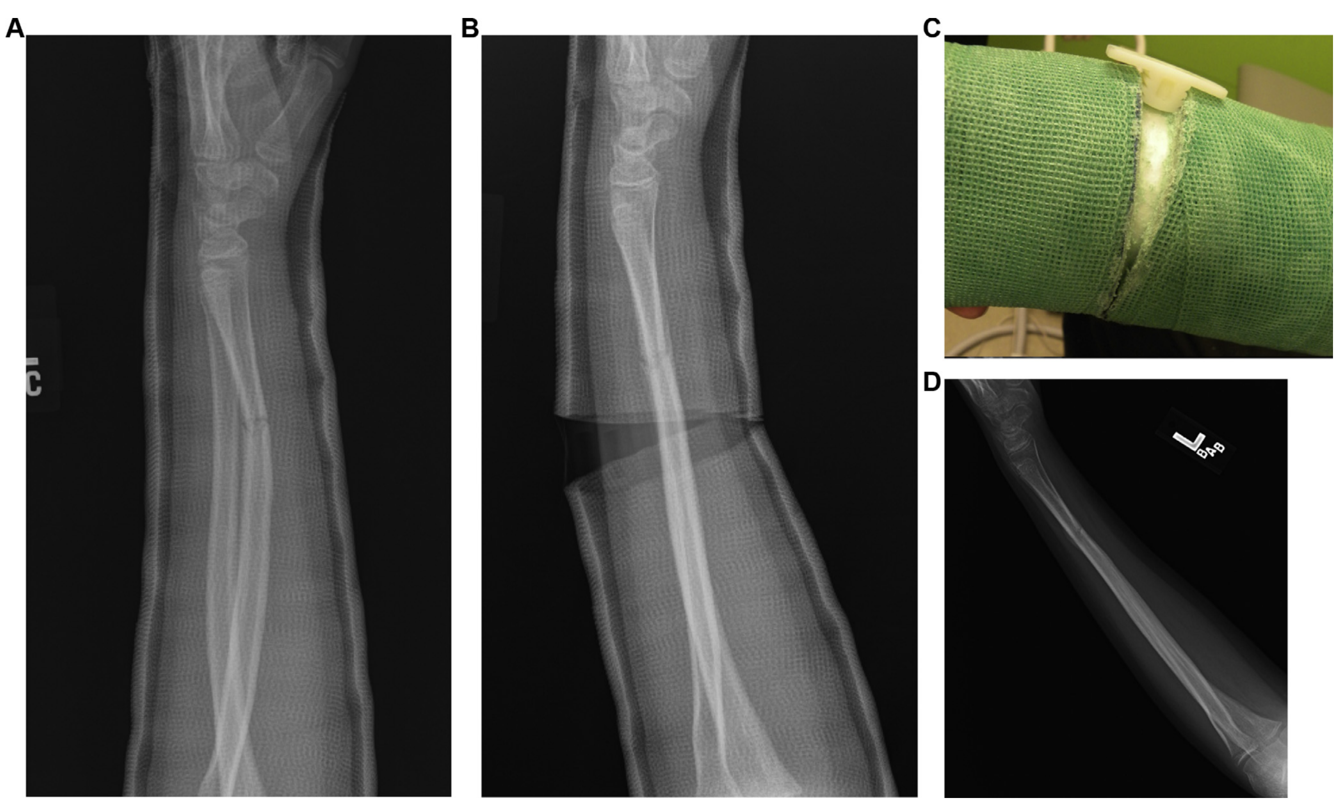

Figure 2 Example of cast wedging. Prewedge (A), postwedge (B), clinical picture of actual wedge (C), and final healing of fracture in good alignment (D).

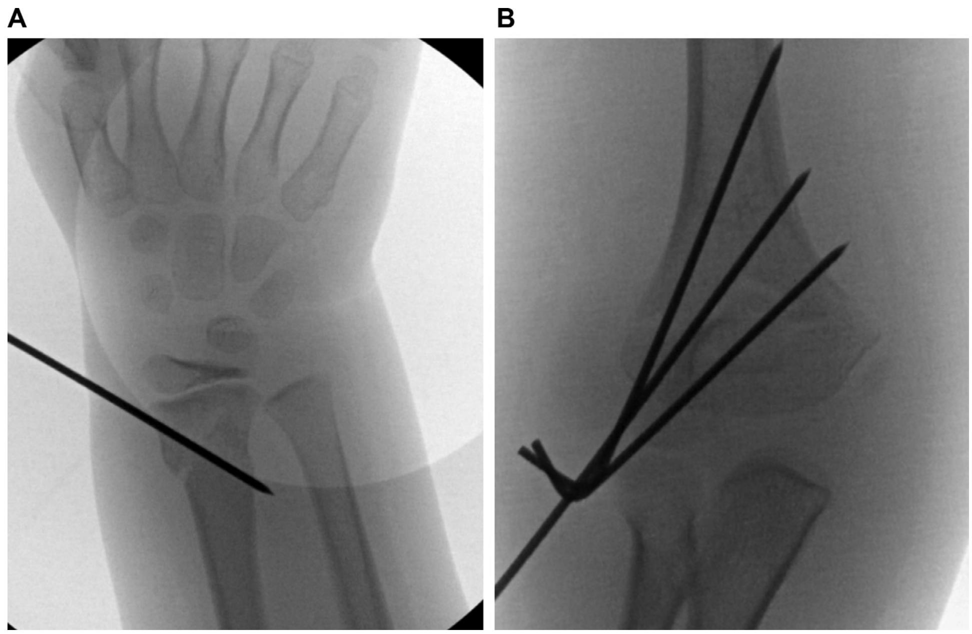

Figure 3 Extraphyseal pinning of a distal radius fracture (A) in a patient with a concomitant supracondylar humerus fracture (B). This construct allows the patient to be placed in a splint or bivalved cast, with less worry for development of compartment syndrome, as there is no need for a well-molded, constrictive cast at the wrist/forearm.

fractures and compared their results to 26 patients who underwent nonintrafocal or conventional pinning technique. There was no difference in angulation on either the AP or lateral radiographs and by 4-6 weeks all fractures went on to union with full pain-free range of motion in both groups. While there was a higher percentage of pin-related complications in the conventional group, the difference was not significant. When compared to closed reduction and long arm casting, McLauchlan[63] demonstrated in a prospective randomized controlled trial, CRPP had significantly better maintenance of reduction and fewer follow-up radiographs. In addition, there was no difference in functional outcome between the 2 groups at 3-month follow-up. However, there was an 11% pin-site complication rate in the CRPP group. Miller[64] compared CRPP to long arm casting and demonstrated that although all fractures went on to unite without deformity, growth arrest, or functional limitations, 39% of patients in the long arm casting group had to undergo remanipulation and casting of their fracture secondary to displacement. This is in comparison to 0% of loss of reduction in the CRPP group. However, 38% of patients in the CRPP group developed pin-related complications (ie, pin migration, infection, pain, and tendon irritation) that eventually resolved without any long-term complications once pins were removed. Cost analysis showed no difference between the 2 groups.

In the rare situation where a distal radius fracture is not amenable to CRPP, then ORIF can be used to obtain and maintain reduction. When there is a very oblique fracture pattern or if the fracture is too proximal (even if it still remains in the distal third), percutaneous fixation may not provide enough biomechanical stability, and ORIF may be the better option.[65] ORIF may be a better option if there is a need for earlier range of motion or weight-bearing activities, such as in poly-trauma patients or high-level athletes. Plate and screw fixation allows direct visualization and anatomic reduction of the fracture, with excellent biomechanical stability. It is important that the plate does not cross the physis and that the screws are of appropriate length to prevent tendon irritation.[65] Disadvantages include the need for a large incision, potential periosteal stripping at the fracture site, and hardware irritation, which can lead to increased infection rates, delayed healing and eventual need for hardware removal.[66]

Complications

Multiple complications can occur in patients treated nonoperatively and operatively with distal radius fractures. A total of 1%-7% of patients who sustain a physeal fracture of the distal radius will go on to physeal arrest.[67,68] When patients present with a displaced physeal fracture, multiple attempts at reduction should be discouraged, as there is an increased risk of iatrogenic physeal injury with increased closed reduction attempts.[69] Furthermore, patients who present more than 10 days postinjury with a physeal fracture should not undergo attempted closed reduction and immobilization as again there is fear of further physeal injury.[65] Follow-up and repeat radiographs should be obtained until normal growth is identified either by parallel Park-Harris lines or an unchanged ulnar variance.[65,70] In patients who sustain a physeal arrest of the distal radius and have more than 2 mm of potential growth remaining, surgical intervention should be considered, as alterations in ulnar variation can lead to altered load transmission across the ulnocarpal joint and ultimately lead to degenerative changes and wrist pain (Fig. 4). Complete radius and distal ulna epiphysiodesis can help prevent further deformity as the child matures. In children who appear to be healing into a malunion it must be taken into consideration that 15°-20° of angulation will normally remodel. In addition, deformity of the distal radius has less of an impact of forearm rotation than middle/proximal radius deformity. Nonetheless, as children mature, angular deformities are less tolerable and less likely to remodel.[71]

Nonunions of pediatric distal radius fractures are rare but do occur and are most commonly associated with disruption of local blood supply secondarily to ORIF.[72,73] Delayed union and radioulnar synostosis are rare complications that can also occur most commonly to either inadequate stabilization and high energy trauma and/or traumatic head injuries, respectively.[74,75]

Kataoka et al[71] describe a computer-planned rotational corrective osteotomy with a custom jig in 4 adolescents with malunited distal radius fractures. Preoperative mean arc of forearm supination was 5° compared to 79° postoperative (range 75°-80°) without any significant loss of pronation. Mean wrist extension improved from 70° to 83° (range 80°-90°), sagittal angulation improved from 12.5° to 1.8° (range 0°-3°), all osteotomies healed by 3 months and there were no major complications reported. In patients with mild to moderate angular deformities with marked limitation in forearm rotation, it is necessary to consider rotational deformities around the distal radius as the pronator quadratus can become contracted leading to discernable rotation of the fracture and ultimate subtle rotational malunions. Surgical intervention should be considered before there are pathologic compensatory changes in the distal radioulnar joint that lead to difficulties performing daily activities.[71]

Scaphoid fractures

Although pediatric scaphoid fractures comprise only 0.39% of all pediatric fractures and 2.2% of all pediatric hand fractures, they account for 87% of all pediatric carpal fractures.[76-78] There is a predilection toward the male sex, with 79%-95% of fractures occurring in males. The majority occur within adolescents 11-15 years of age and rarely happen in patient's less than 9 years of age.[79-81] Historically it was reported that most adolescent scaphoid fractures occurred at the distal pole, compromising 59-87% of all scaphoid fractures.[76,81-84] However, Gholson[85] and Garala[83] retrospectively reviewed 351 and 415 pediatric scaphoid fractures, respectively. They found waist fractures to be significantly more common (64%-70.7%). It has been postulated[85] that the reason we are seeing these adult-type injuries in the pediatric population is related to an increased BMI in patients as well as increased participation in high-energy and high-impact sports. Gholson[85] found that when the mechanism for a scaphoid fracture was due to high energy, the fracture most commonly occurred through the waist (78.6%).

Pathoanatomy

The scaphoid is the only bone to bridge both carpal rows, with the proximal pole articulating with the scaphoid fossa of the distal radius as well as the lunate and the distal pole articulating with the trapezium and trapezoid thus forming the scaphotrapeziotrapezoid joint. The scaphoid blood supply includes the dorsal carpal branch of the radial artery and the volar scaphoid artery by way of the superficial palmar arch. The dorsal carpal branch courses along the dorsal ridge and supplies blood in a retrograde fashion to the proximal 70%-80% of the scaphoid. The volar scaphoid artery supplies the distal 20%-30% of the scaphoid with Gelberman[86] demonstrating no anastomosis between the vasculature in 15 fresh cadaver specimens.

When treating pediatric patients, it is important to understand the ossification timeline. The ossific nucleus of the scaphoid appears in males around 5-6 years and females 4-5 years, with enchondral ossification completing at 15 and 13 years of age for males and females, respectively. D'Arienzo[84] classified scaphoids into 3 types. Type 1 occurs in children less than 8 years of age with a fracture that is either purely chondral or involves part of the ossific nucleus (these fractures typically require the assistance of magnetic resonance imaging [MRI] for definitive diagnosis). Type 2 occurs in children 8-11 years and includes an osteochondral fragment. Type 3 occurs in ages greater than 12 and is the most common type with clearly visible osseous fractures.

Part of the challenge of pediatric scaphoid fractures is the diagnosis as the patient may have physical symptoms but negative radiographic evidence. Evenski[87] found that 31/104 (30%) of patients who initially presented to the emergency department with a high suspicion for a scaphoid fracture but negative radiographs demonstrated radiographic evidence of a fracture on initial follow-up. Most patients will present with a history detailing a hyperextension injury to the wrist. Weber[88] was able to demonstrate that at 95° or more of wrist extension and radial deviation, a 4x increase in force is transmitted to the scaphoid with a majority concentrated at the waist. Hyperextension, hyperflexion, and ulnar deviation patterns have also been reported. In the acute setting, swelling of the distal radius/carpus, limited range or motion, and tenderness to palpation in the anatomic snuffbox and scaphoid tubercle volarly are usually present. Evenski was also able to determine that volar tenderness (P = 0.010), radial deviation (P = 0.001), and pain with active range of motion (P = 0.015) were significant clinical predictors of scaphoid fractures with negative initial radiographs.

Imaging

It is important to recognize that up to 37% of fractures may not be radiographically present until follow-up radiographs. A total of 84% of clinically suspected fractures not seen at first follow-up will be radiographically evident at the second visit (2-9 weeks postinjury).[76,77,87] Nonetheless, obtaining adequate radiographic views of the scaphoid (including a

Figure 4 AP (A) and lateral (B) radiographs of a 13-year-old male with a Salter Harris II distal radius fracture that underwent closed reduction and casting (C and D). He went on to develop premature physeal closure of his radius, and had symptomatic ulnar impaction syndrome due to positive ulnar variance (E), for which he underwent an ulnar shortening osteotomy (F), with complete resolution of his symptoms.

navicular view) will help identify any potential pathology. A navicular view is taken with the wrist in 30° of extension and 20° of ulnar deviation. This view takes into account the flexed position of the scaphoid and will limit the amount of surrounding carpal overlap. A true lateral film will show the pisiform overlying the central third of the interval between the palmar cortex of the distal pole of the scaphoid and head of the capitate.[89] A lateral film helps the surgeon identify and measure several important carpal relationships. The capitolunate angle should be <30° with an increase indicating a potential dorsal intercalated segmental instability deformity. The scapholunate angle should be measured between 30°

and 60°, and the intrascaphoid angle measured at 40° ± 3°. Variations in these angles help identify potential underlying carpal instability and scaphoid deformities.

Further advanced imaging has been utilized to help with identifying and diagnosing fractures. Bone scans have been used for suspected occult fractures demonstrating a sensitivity of 100% and specificity of 98%, with a positive predictive value (PPV) of 85%-93% at 72 hours. However, a recent Cochrane review[90] looking at the most suitable imaging for clinically suspected fractures with negative radiographs stated that "while a bone scan is statistically the best modality to establish a diagnosis in a clinically suspected fracture, it is more invasive than other modalities (MRI, computed tomography [CT]) and has a risk of increased radiation exposure with a diagnostic delay of at least 72 hours."

CT scans have also been utilized to aid in diagnosis. With a sensitivity of 85.2% and specificity of 99.5% they are less sensitive than an MRI with the added risk of increased radiation exposure. However, they do aid in identifying the location of fractures, the progression of nonunion or union after surgery, the sites of fragmentation and the extent of potential collapse.[90,91] MRI has received attention as a potential tool to diagnose occult fractures quickly after injury, and potentially avoids unnecessary immobilization. MRIs demonstrate a sensitivity of 97.7%, specificity of 99.8%, and a negative predictive value (NPV) of 100%. Johnson[92] looked at 56 patients who presented with clinically suspicious injuries but negative initial radiographs and received an MRI within 10 days postinjury. He found that 75% of patients who were diagnosed with a scaphoid fracture on MRI had negative initial radiographs. Furthermore, 33/58 (58%) patients had negative radiographs and a negative MRI, thus potentially eliminate the need for follow-up radiographs and immobilization in 58% of patients. Jorgsholm[93] looked at 89 patients with radial-sided wrist pain after a trauma and received initial radiographs and both a CT and MRI. They found that MRIs diagnosed 74 total fractures including 48 scaphoid fractures. Radiographs and CT imaging were able to diagnose 34 (26 scaphoid fractures) and 53 (43 scaphoid fractures) of the same fractures, respectively. Initial imaging, advanced imaging, and high clinical suspicion must be used to either rule out or identify associate injuries as there is a 15% incidence of associated fractures with distal radius, ulnar styloid, and transcaphoid perilunate dislocations being some of the most common.[85]

Treatment

Nonoperative

Cast immobilization has been the standard of nonoperative treatment for pediatric and adolescent scaphoid fractures. Patients who present with acute nondisplaced scaphoid fractures or suspected scaphoid fractures should undergo cast immobilization with radiographic follow-up in 2 weeks as more than 90% of patients will achieve union.[85] Debate exists among surgeons on using above- vs below-elbow casts. Gellman[94] compared time to union in a prospective study of 28 patients placed in an above-elbow cast vs 23 in a below-elbow cast. He found a fast time to union in the above elbow group, 9.5 weeks compared to 12.7 weeks in the below-elbow group. Shaterian[95] performed a meta-analysis of 812 acute pediatric scaphoid fractures of which 93.5% were treated in a cast. He found no significant difference in union rates among those patients treated in an above-elbow thumb spica cast (100%) vs below-elbow thumb spica cast (97.4%). In addition, Doornberg[96] in a meta-analysis of 523 adult patients also found no evidence to favor one method of immobilization over another. Biomechanical cadaveric data are also conflicting with studies[97-99] stating that above-elbow cast may be unnecessary and below cast adequate for immobilization while others[100] state that there is unacceptable motion at the scaphoid fracture site without above-elbow thumb spica immobilization. Another controversial notion in cast immobilization is thumb immobilization. Historically treatment has included immobilization of the thumb for fear of thumb motion causing excessive motion at the scaphoid fracture site. Buijze[101] completed a prospective randomized controlled trial comparing 62 patients with minimally and nondisplaced scaphoid waist fractures treated with below-elbow casts without or without thumb immobilization. After 10 weeks overall, union rate was 98% with patients in the below-elbow cast without thumb immobilization demonstrating 85% union seen on CT scan as bridging bone compared to 70% in the thumb immobilization group. He further found no significant differences in wrist motion, pain, grip strength, pain scores, DASH scores, and Modified Mayo wrist score. Kawanishi et al[102] performed an in vivo study looking at scaphoid motion with motion of the thumb and forearm utilizing 3D CT scans. They created 2 groups utilizing healthy volunteers. The first group was placed into a below-elbow thumb spica cast and had CT scans of their wrist hand with the forearm in pronation, neutral, and supination. They then removed the thumb spica component of the cast and performed the CT scans again, this time with the forearm in neutral with the thumb fully abducted and then fully opposed. Their results demonstrated that motion that occurs at the scaphoid with forearm rotation and thumb motion may not be sufficient enough to have a negative impact on the outcomes of scaphoid fracture healing utilizing cast immobilization. Length of time for cast immobilization is also a source of debate. Historically it has been thought that proximal pole fractures may require 12-24 weeks of immobilization while waist and distal pole fractures require 8-12 weeks and 6-8 weeks of cast treatment, respectively.

There are several factors that have been found to lead to potential delayed healing with cast treatment in the pediatric population.[85] These include fracture location, fracture displacement, delayed time to initial treatment, and presence of osteonecrosis. Displaced fractures take on average 12 weeks longer to achieve union compared to nondisplaced fractures (19 weeks vs 7 weeks). Acute fractures achieve union 10 weeks earlier than chronic fractures (6 weeks vs 16 weeks). Finally, the presence of osteonecrosis increased time to union by 3 weeks (13 weeks vs 10 weeks). It is important to recognize the expected functional outcomes after cast immobilization, as this is usually a significant amount of time the patient will be immobilized. Ahmed[81] looked at 56 patients with a mean follow-up of 70 months and found 60% had no lasting functional limitations, no patients had substantial limitations in their daily functional activities and 25% reported only mild or infrequent problems during sporting activities. Bae et al[103] in their study of 63 patients with 6.3-year follow-up found that all fractures healed with 95% excellent functional outcomes and Modified Mayo wrist scores and DASH scores were comparable to the general population. He also found that surgery did not influence functional outcomes and the independent predictors of worse outcomes were chronic fractures and the presence of osteonecrosis. When the authors looked at all of the chronic fractures who initially underwent casting (17/34) he found that 4 (23.5%) achieved union while 13 (76.4%) eventually had surgery and went on to union.

The treatment of acute nondisplaced fractures in the pediatric population is controversial. The controversy arises as greater than 90% union rates are reported in adolescents treated nonoperatively without the risks of operative intervention. Bond[104] found faster radiographic and clinical time to union (7weeks vs 12 weeks) in adolescent patients who underwent percutaneous screw fixation of acute nondisplaced fractures compared to cast immobilization. When approaching the acute nondisplaced scaphoid waist fracture, both the percutaneous dorsal and volar approaches are appropriate options. The dorsal approach allows increased ease of access to the central axis of the scaphoid. Placement of the compression screw within the central axis has demonstrated increased stiffness of the construct, increased rate of healing and decreased risk of screw penetration.[105,106] The volar approach leads to an increased risk of scaphotrapezial joint penetration and possible arthritis. When comparing percutaneous dorsal vs volar approaches Kang et al[107] found while there was increased ulnar deviation with the volar approach, there was no difference in functional outcomes, post-op pain, grip strength, and range of motion. Jeon[108] was able to demonstrate that screws placed via the dorsal approach were more parallel to the long axis of the scaphoid. Nevertheless, there was no reported difference in functional outcomes or bony union. Finally, Polsky[109] also reported no differences in range of motion, grip strength, or pain levels when comparing the 2 percutaneous approaches.

While the vast majority of patients will achieve union with nonoperative treatment,[85,95] there are times when operative intervention is necessary. Acute displaced fractures, chronic nondisplaced and displaced fractures, as well as failure of conservative treatment are all indications for surgical intervention.

When faced with an acute displaced fracture the surgeon must be aware of the factors that contribute to an unstable fracture. Displacement >1 mm, 15° humpback deformity, intrascaphoid angle >35°, radiolunate angle >15°, comminution at the fracture site, vertical or oblique fracture patterns, proximal pole fractures, and associated perilunate injuries all have been found to be predictive of an unstable fracture.[110] When approaching these displaced fractures, either the dorsal or volar approach can be utilized. The dorsal approach is helpful with proximal pole fractures, but one must be cognizant of the blood supply entering the dorsal ridge and limit distal exposure and capsular retraction. The volar approach is utilized with waist and distal pole fractures as well as the presence of humpback deformity. It is easy to obtain visualization of the entire scaphoid as there is not as high of an iatrogenic risk to the blood supply.

The surgical treatment of nonunions in the pediatric patient is relatively rare as 96% to 98% of patients achieve union with cast immobilization. However, almost 30% of patients will present with a chronic scaphoid fracture and of those treated in a cast, >65% will continue to progress to a nonunion.[85] The presence of a nonunion increases the likelihood of additional deformities that must be addressed. When presented with a dorsal intercalated segmental instability deformity, the placement of a radiolunate k-wire can be utilized to restore neutral alignment before fixation of the scaphoid.[111] Humpback deformities of the scaphoid occur because of flexion of the distal fragment. The placement of 2 k-wires, perpendicular to the fragments, can act as joysticks to help obtain better control of each fragment. If there is difficulty in obtaining correct reduction of the fragments, utilizing the articular border of the capitate as a guide can help obtain reduction.

There are multiple options for the utilization of bone graft including distal radius, iliac crest, and vascularized grafts. Cohen et al[112] found that distal radius cancellous autograft is sufficient to treat scaphoid waist nonunions even with humpback deformity. The advantage is a much simpler surgery, no need for morbidity in obtaining a nonlocal graft, rapid incorporation of the cancellous bone, and a shorter surgery (Fig. 5). Jauregui[113] performed a meta-analysis on the operative management of scaphoid nonunions and found when comparing 157 nonvascularized bone grafts to 19 cases without bone grafting, the union rates were equivocal at 94.8% and 94.6%, respectively. In addition, there were 4 complications in the bone grafting group compared to none in the nonbone grafting group. While vascularized bone grafts are more common in the adult population, there are several reports on the utilization of the distal radius and medial femoral condyle vascularized grafts in adolescent patients. Waters and Stewart[114] reported on 3 patients all with proximal pole avascular necrosis (AVN) and an average age of 14.3 years who went on to union at 3.4 months treated with a distal radius vascularized graft. Ben-Amotz[115] reported on a 17-year-old male with complete AVN of the scaphoid, who went on to union with a medial femoral condyle graft. Braga-Silvia[116] compared the outcomes of 35 patients treated with a distal radius vascularized graft to 45 patients treated with a nonvascularized iliac crest graft. He found no significant difference in union rates, time to union, and functional results. Gholson[85] looked at the outcomes of nonunions after surgery and found a 96% union rate compared to 98% of acute fractures treated surgically. Functionally, 95% of adolescents with nonunions who undergo surgery will achieve functional status that is better than or equal to the general population.[103]

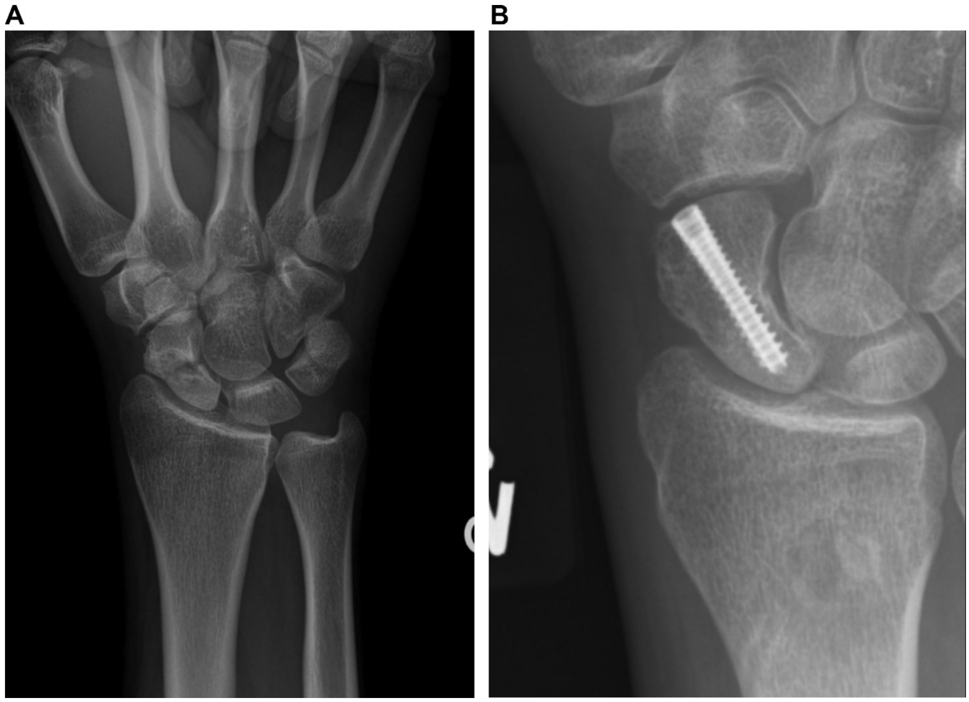

Figure 5 Seventeen-year-old male with an approximately 7-month-old scaphoid waist nonunion (A), who underwent open reduction with use of distal radius cancellous autograft and screw fixation, and healed 12 weeks later (B).

Conclusions

Pediatric patients often do well with conservative management of wrist injuries. There are, however, certain injuries that require operative intervention. Distal radius fractures can be treated with closed reduction and casting, CRPP, and ORIF. Acute nondisplaced scaphoid fractures do well with casting, but there is some evidence that there is quicker time to union with percutaneous screw fixation. Scaphoid fracture nonunions do well with distal radius autograft and screw fixation alone, without the need for vascularized grafting.

References

1. Nellans KW, Kowalski E, Chung KC: The epidemiology of distal radius fractures. Hand Clin 28:113-125, 2012
2. Randsborg PH, Gulbrandsen P, Saltyte Benth J, et al: Fractures in children: Epidemiology and activity-specific fracture rates. J Bone Jt Surg Am 95:e42, 2013
3. Ward WT, Rihn JA: The impact of trauma in an urban pediatric orthopaedic practice. J Bone Jt Surg Am 88:2759-2764, 2006
4. Landin LA: Fracture patterns in children. Analysis of 8,682 fractures with special reference to incidence, etiology and secular changes in a Swedish urban population 1950-1979. Acta Orthop Scand Suppl 202:1-109, 1983
5. Cheng JC, Shen WY: Limb fracture pattern in different pediatric age groups: A study of 3,350 children. J Orthop Trauma 7:15-22, 1993
6. Worlock P, Stower M: Fracture patterns in Nottingham children. J Pediatr Orthop 6:656-660, 1986
7. Skaggs DL, Loro ML, Pitukcheewanont P, et al: Increased body weight and decreased radial cross-sectional dimensions in girls with forearm fractures. J Bone Miner Res 16:1337-1342, 2001
8. Goulding A, Jones IE, Taylor RW, et al: Bone mineral density and body composition in boys with distal forearm fractures: A dual-energy x-ray absorptiometry study. J Pediatr 139:509-515, 2001
9. Khosla S, Melton LJ 3rd, Dekutoski MB, et al: Incidence of childhood distal forearm fractures over 30 years: A population-based study. JAMA 290:1479-1485, 2003
10. Bae DS, Howard AW: Distal radius fractures: What is the evidence? J Pediatr Orthop 32(Suppl 2):S128-S130, 2012
11. Chung KC, Spilson SV: The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg Am 26:908-915, 2001
12. Krabbe S, Christiansen C, Rodbro P, et al: Effect of puberty on rates of bone growth and mineralisation: With observations in male delayed puberty. Arch Dis Child 54:950-953, 1979
13. Faulkner RA, Davison KS, Bailey DA, et al: Size-corrected BMD decreases during peak linear growth: Implications for fracture incidence during adolescence. J Bone Miner Res 21:1864-1870, 2006
14. Leonard MB, Zemel BS, Wrotniak BH, et al: Tibia and radius bone geometry and volumetric density in obese compared to non-obese adolescents. Bone 73:69-76, 2015
15. Pollock NK: Childhood obesity, bone development, and cardiometabolic risk factors. Mol Cell Endocrinol 410:52-63, 2015
16. Whiting SJ: Obesity is not protective for bones in childhood and adolescence. Nutr Rev 60:27-30, 2002
17. Kim SJ, Ahn J, Kim HK, et al: Obese children experience more extremity fractures than nonobese children and are significantly more likely to die from traumatic injuries. Acta Paediatr 105:1152-1157, 2016
18. Adams AL, Kessler JI, Deramerian K, et al: Associations between childhood obesity and upper and lower extremity injuries. Inj Prev 19:191-197, 2013
19. Pomerantz WJ, Timm NL, Gittelman MA: Injury patterns in obese versus nonobese children presenting to a pediatric emergency department. Pediatrics 125:681-685, 2010
20. Leet AI, Pichard CP, Ain MC: Surgical treatment of femoral fractures in obese children: Does excessive body weight increase the rate of complications? J Bone Jt Surg Am 87:2609-2613, 2005
21. Chang CH, Kao HK, Lee WC, et al: Influence of obesity on surgical outcomes in type III paediatric supracondylar humeral fractures. Injury 46:2181-2184, 2015
22. Lazar-Antman MA, Leet AI: Effects of obesity on pediatric fracture care and management. J Bone Jt Surg Am 94:855-861, 2012

23. Douma-den Hamer D, Blanker MH, Edens MA, et al: Ultrasound for distal forearm fracture: A systematic review and diagnostic meta-analysis. PLoS One 11:e0155659, 2016
24. Waters PM, Bae DS: Fractures of the distal radius and ulna. In: Beaty JH, Kasser JR (eds): Rockwood and Wilkins' Fractures in Children, Philadelphia, Pa: Lippincott, Williams & Wilkinis, 292-346, 2018
25. Digby KH: The measurement of diaphysial growth in proximal and distal directions. J Anat Physiol 50:187-188, 1916
26. Bae DS, Waters PM: Pediatric distal radius fractures and triangular fibrocartilage complex injuries. Hand Clin 22:43-53, 2006
27. Fung EB, Humphrey ML, Gildengorin G, et al: Rapid remineralization of the distal radius after forearm fracture in children. J Pediatr Orthop 31:138-143, 2011
28. Ko C, Baird M, Close M, et al: The diagnostic accuracy of ultrasound in detecting distal radius fractures in a pediatric population. Clin J Sport Med 15:0000000000000547, 2017
29. Hedelin H, Tingstrom C, Hebelka H, et al: Minimal training sufficient to diagnose pediatric wrist fractures with ultrasound. Crit Ultrasound J 9:11, 2017
30. Schoenecker JG, Bae DS: Fractures of the distal radius and ulna. In: Flynn JM, Skaggs DL, Waters PM, eds. Rockwood and Wilkins' Fractures in Children. Philadelphia, Pa: Wolters Kluwer, 349-412
31. Herring J: Tachdjian's Pediatric Orthopaedics. Philadelphia, Pa: Elsevier, 2014
32. Farbman KS, Vinci RJ, Cranley WR, et al: The role of serial radiographs in the management of pediatric torus fractures. Arch Pediatr Adolesc Med 153:923-925, 1999
33. Davidson JS, Brown DJ, Barnes SN, et al: Simple treatment for torus fractures of the distal radius. J Bone Jt Surg Br 83:1173-1175, 2001
34. Oakley EA, Ooi KS, Barnett PL: A randomized controlled trial of 2 methods of immobilizing torus fractures of the distal forearm. Pediatr Emerg Care 24:65-70, 2008
35. Plint AC, Perry JJ, Correll R, et al: A randomized, controlled trial of removable splinting versus casting for wrist buckle fractures in children. Pediatrics 117:691-697, 2006
36. West S, Andrews J, Bebbington A, et al: Buckle fractures of the distal radius are safely treated in a soft bandage: A randomized prospective trial of bandage versus plaster cast. J Pediatr Orthop 25:322-325, 2005
37. Kuba MHM, Izuka BH: One brace: One visit: Treatment of pediatric distal radius buckle fractures with a removable wrist brace and no follow-up visit. J Pediatr Orthop 9:0000000000001169, 2018
38. Ling SJ, Cleary AJ: Are unnecessary serial radiographs being ordered in children with distal radius buckle fractures? Radiol Res Pract 2018:5143639, 2018
39. Bernthal NM, Mitchell S, Bales JG, et al: Variation in practice habits in the treatment of pediatric distal radius fractures. J Pediatr Orthop B 24:400-407, 2015
40. Dua K, Stein MK, O'Hara NN, et al: Variation among pediatric orthopaedic surgeons when diagnosing and treating pediatric and adolescent distal radius fractures. J Pediatr Orthop 27:0000000000000954, 2017
41. 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 182:1507-1512, 2010
42. Bohm ER, Bubbar V, Yong Hing K, et al: Above and below-the-elbow plaster casts for distal forearm fractures in children. A randomized controlled trial. J Bone Jt Surg Am 88:1-8, 2006
43. Webb GR, Galpin RD, Armstrong DG: Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. J Bone Jt Surg Am 88:9-17, 2006
44. Boyer BA, Overton B, Schrader W, et al: Position of immobilization for pediatric forearm fractures. J Pediatr Orthop 22:185-187, 2002
45. Ting BL, Kalish LA, Waters PM, et al: Reducing cost and radiation exposure during the treatment of pediatric greenstick fractures of the forearm. J Pediatr Orthop 36:816-820, 2016
46. Bear DM, Friel NA, Lupo CL, et al: Hematoma block versus sedation for the reduction of distal radius fractures in children. J Hand Surg Am 40:57-61, 2015
47. Luhmann JD, Schootman M, Luhmann SJ, et al: A randomized comparison of nitrous oxide plus hematoma block versus ketamine plus midazolam for emergency department forearm fracture reduction in children. Pediatrics 118:e1078-e1086, 2006
48. Tseng PT, Leu TH, Chen YW, et al: Hematoma block or procedural sedation and analgesia, which is the most effective method of anesthesia in reduction of displaced distal radius fracture? J Orthop Surg Res 13:62, 2018
49. Iltar S, Alemdaroglu KB, Say F, et al: The value of the three-point index in predicting redisplacement of diaphyseal fractures of the forearm in children. Bone Joint J 95-B:563-567, 2013
50. Kamat AS, Pierse N, Devane P, et al: Redefining the cast index: The optimum technique to reduce redisplacement in pediatric distal forearm fractures. J Pediatr Orthop 32:787-791, 2012
51. Williams ND, Rush JK, Schmitz MR, et al: Reliability of casting indices among members of an orthopaedic surgery residency. J Pediatr Orthop 37:e238-e242, 2017
52. Abson S, Williams N, Inglis M, et al: Resident versus attending surgeons in achieving and maintaining fracture reduction in pediatric distal radius fractures. J Pediatr Orthop 36:478-482, 2016
53. Sumko MJ, Hennrikus W, Slough J, et al: Measurement of radiation exposure when using the mini C-arm to reduce pediatric upper extremity fractures. J Pediatr Orthop 36:122-125, 2016
54. Gendelberg D, Hennrikus W, Slough J, et al: A radiation safety training program results in reduced radiation exposure for orthopaedic residents using the mini C-arm. Clin Orthop Relat Res 474:580-584, 2016
55. Gendelberg D, Hennrikus WL, Sawyer C, et al: Decreased radiation exposure among orthopedic residents is maintained when using the mini C-arm after undergoing radiation safety training. Orthopedics 40: e788-e792, 2017
56. Luther G, Miller P, Waters PM, et al: Radiographic evaluation during treatment of pediatric forearm fractures: Implications on clinical care and cost. J Pediatr Orthop 36:465-471, 2016
57. Robert CE, Jiang JJ, Khoury JG: A prospective study on the effectiveness of cotton versus waterproof cast padding in maintaining the reduction of pediatric distal forearm fractures. J Pediatr Orthop 31:144-149, 2011
58. Auer RT, Mazzone P, Robinson L, et al: Childhood obesity increases the risk of failure in the treatment of distal forearm fractures. J Pediatr Orthop 36:e86-e88, 2016
59. Samora JB, Klingele KE, Beebe AC, et al: Is there still a place for cast wedging in pediatric forearm fractures? J Pediatr Orthop 34:246-252, 2014
60. Gaukel S, Leu S, Fink L, et al: Cast wedging: A systematic review of the present evidence. J Child Orthop 11:398-403, 2017
61. Khandekar S, Tolessa E, Jones S: Displaced distal end radius fractures in children treated with Kirschner wires – A systematic review. Acta Orthop Belg 82:681-689, 2016
62. Parikh SN, Jain VV, Youngquist J: Intrafocal pinning for distal radius metaphyseal fractures in children. Orthopedics 36:783-788, 2013
63. McLauchlan GJ, Cowan B, Annan IH, et al: Management of completely displaced metaphyseal fractures of the distal radius in children. A prospective, randomised controlled trial. J Bone Joint Surg Br 84:413-417, 2002
64. Miller BS, Taylor B, Widmann RF, et al: Cast immobilization versus percutaneous pin fixation of displaced distal radius fractures in children: A prospective, randomized study. J Pediatr Orthop 25:490-494, 2005
65. Dua K, Abzug JM, Sesko Bauer A, et al: Pediatric distal radius fractures. Instr Course Lect 66:447-460, 2017
66. Dolan M, Waters PM: Fractures and dislocations of the forearm, wrist, and hand. In: Green NE, Swiontkowski MD (eds): Skeletal Trauma in Children, Philadelphia, Pa: Saunders, 159-206, 2008
67. Buterbaugh GA, Palmer AK: Fractures and dislocations of the distal radioulnar joint. Hand Clin 4:361-375, 1988
68. Lee BS, Esterhai JL Jr., Das M: Fracture of the distal radial epiphysis. Characteristics and surgical treatment of premature, post-traumatic epiphyseal closure. Clin Orthop Relat Res 185:90-96, 1984
69. Valverde JA, Albinana J, Certucha JA: Early posttraumatic physeal arrest in distal radius after a compression injury. J Pediatr Orthop B 5:57-60, 1996

70. Abzug JM, Little K, Kozin SH: Physeal arrest of the distal radius. J Am Acad Orthop Surg 22:381-389, 2014
71. Kataoka T, Oka K, Murase T: Rotational corrective osteotomy for malunited distal diaphyseal radius fractures in children and adolescents. J Hand Surg Am 43, 2018. 286 e281-286 e288
72. Lewallen RP, Peterson HA: Nonunion of long bone fractures in children: A review of 30 cases. J Pediatr Orthop 5:135-142, 1985
73. Fernandez FF, Eberhardt O, Langendorfer M, et al: Nonunion of forearm shaft fractures in children after intramedullary nailing. J Pediatr Orthop B 18:289-295, 2009
74. De Raet J, Kemnitz S, Verhaven E: Nonunion of a pediatric distal radial metaphyseal fracture following open reduction and internal fixation: A case report and review of the literature. Eur J Trauma Emerg Surg 34:173-176, 2008
75. Noonan KJ, Price CT: Forearm and distal radius fractures in children. J Am Acad Orthop Surg 6:146-156, 1998
76. Christodoulou AG, Colton CL: Scaphoid fractures in children. J Pediatr Orthop 6:37-39, 1986
77. Nafie SA: Fractures of the carpal bones in children. Injury 18:117-119, 1987
78. Brudvik C, Hove LM: Childhood fractures in Bergen, Norway: Identifying high-risk groups and activities. J Pediatr Orthop 23:629-634, 2003
79. Toh S, Miura H, Arai K, et al: Scaphoid fractures in children: Problems and treatment. J Pediatr Orthop 23:216-221, 2003
80. Gajdobranski D, Zivanovic D, Mikov A, et al: Scaphoid fractures in children. Srp Arh Celok Lek 142:444-449, 2014
81. Ahmed I, Ashton F, Tay WK, et al: The pediatric fracture of the scaphoid in patients aged 13 years and under: An epidemiological study. J Pediatr Orthop 34:150-154, 2014
82. Vahvanen V, Westerlund M: Fracture of the carpal scaphoid in children. A clinical and roentgenological study of 108 cases. Acta Orthop Scand 51:909-913, 1980
83. Garala K, Taub NA, Dias JJ: The epidemiology of fractures of the scaphoid: Impact of age, gender, deprivation and seasonality. Bone Jt J 98-B:654-659, 2016
84. D'Arienzo M: Scaphoid fractures in children. J Hand Surg Br 27: 424-426, 2002
85. Gholson JJ, Bae DS, Zurakowski D, et al: Scaphoid fractures in children and adolescents: Contemporary injury patterns and factors influencing time to union. J Bone Jt Surg Am 93:1210-1219, 2011
86. Gelberman RH, Menon J: The vascularity of the scaphoid bone. J Hand Surg Am 5:508-513, 1980
87. Evenski AJ, Adamczyk MJ, Steiner RP, et al: Clinically suspected scaphoid fractures in children. J Pediatr Orthop 29:352-355, 2009
88. Weber ER, Chao EY: An experimental approach to the mechanism of scaphoid waist fractures. J Hand Surg Am 3:142-148, 1978
89. Goldfarb CA, Yin Y, Gilula LA, et al: Wrist fractures: What the clinician wants to know. Radiology 219:11-28, 2001
90. Mallee WH, Wang J, Poolman RW, et al: Computed tomography versus magnetic resonance imaging versus bone scintigraphy for clinically suspected scaphoid fractures in patients with negative plain radiographs. Cochrane Database Syst Rev 5:CD010023, 2015
91. Yin ZG, Zhang JB, Kan SL, et al: Diagnostic accuracy of imaging modalities for suspected scaphoid fractures: Meta-analysis combined with latent class analysis. J Bone Jt Surg Br 94:1077-1085, 2012
92. Johnson KJ, Haigh SF, Symonds KE: MRI in the management of scaphoid fractures in skeletally immature patients. Pediatr Radiol 30:685-688, 2000
93. Jorgsholm P, Thomsen N, Besjakov J, et al: MRI shows a high incidence of carpal fractures in children with posttraumatic radial-sided wrist tenderness. Acta Orthop 87:533-537, 2016
94. Gellman H, Caputo RJ, Carter V, et al: Comparison of short and long thumb-spica casts for non-displaced fractures of the carpal scaphoid. J Bone Jt Surg Am 71:354-357, 1989
95. 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 1:1558944717735948, 2017
96. Doornberg JN, Buijze GA, Ham SJ, et al: Nonoperative treatment for acute scaphoid fractures: A systematic review and meta-analysis of randomized controlled trials. J Trauma 71:1073-1081, 2011
97. Romdhane L, Chidgey L, Miller G, et al: Experimental investigation of the scaphoid strain during wrist motion. J Biomech 23:1277-1284, 1990
98. McAdams TR, Spisak S, Beaulieu CF, et al: The effect of pronation and supination on the minimally displaced scaphoid fracture. Clin Orthop Relat Res 411:255-259, 2003
99. McAdams TR, Srivastava S: Arthroscopic evaluation of scaphoid waist fracture stability and the role of the radioscaphocapitate ligament. Arthroscopy 20:152-157, 2004
100. Kaneshiro SA, Failla JM, Tashman S: Scaphoid fracture displacement with forearm rotation in a short-arm thumb spica cast. J Hand Surg Am 24:984-991, 1999
101. Buijze GA, Goslings JC, Rhemrev SJ, et al: Cast immobilization with and without immobilization of the thumb for nondisplaced and minimally displaced scaphoid waist fractures: A multicenter, randomized, controlled trial. J Hand Surg Am 39:621-627, 2014
102. Kawanishi Y, Oka K, Tanaka H, et al: In vivo scaphoid motion during thumb and forearm motion in casts for scaphoid fractures. J Hand Surg Am 42, 2017. 475 e471-475 e477
103. Bae DS, Gholson JJ, Zurakowski D, et al: Functional outcomes after treatment of scaphoid fractures in children and adolescents. J Pediatr Orthop 36:13-18, 2016
104. Bond CD, Shin AY, McBride MT, et al: Percutaneous screw fixation or cast immobilization for nondisplaced scaphoid fractures. J Bone Jt Surg Am 83-A:483-488, 2001
105. McCallister WV, Knight J, Kaliappan R, et al: Central placement of the screw in simulated fractures of the scaphoid waist: A biomechanical study. J Bone Jt Surg Am 85-A:72-77, 2003
106. Trumble TE, Gilbert M, Murray LW, et al: Displaced scaphoid fractures treated with open reduction and internal fixation with a cannulated screw. J Bone Jt Surg Am 82:633-641, 2000
107. Kang KB, Kim HJ, Park JH, et al: Comparison of Dorsal and volar percutaneous approaches in acute scaphoid fractures: A meta-analysis. PLoS One 11:e0162779, 2016
108. Jeon IH, Micic ID, Oh CW, et al: Percutaneous screw fixation for scaphoid fracture: A comparison between the dorsal and the volar approaches. J Hand Surg Am 34:228-236, 2009. e221
109. Polsky MB, Kozin SH, Porter ST, et al: Scaphoid fractures: dorsal versus volar approach. Orthopedics 25:817-819, 2002
110. Geissler W, Slade JF, et al: Fractures of the carpal bones. In: Wolfe SW, Pedersen WC, Hotchkiss RN, et al (eds): Green's Operative Hand Surgery, Philadelphia, Pa: Elsevier, 639-708, 2011
111. Tomaino MM, King J, Pizillo M: Correction of lunate malalignment when bone grafting scaphoid nonunion with humpback deformity: Rationale and results of a technique revisited. J Hand Surg Am 25:322-329, 2000
112. Cohen MS, Jupiter JB, Fallahi K, et al: Scaphoid waist nonunion with humpback deformity treated without structural bone graft. J Hand Surg Am 38:701-705, 2013
113. Jauregui JJ, Seger EW, Hesham K, et al: Operative management for pediatric and adolescent scaphoid nonunions: A meta-analysis. J Pediatr Orthop 15:0000000000000916, 2017
114. Waters PM, Stewart SL: Surgical treatment of nonunion and avascular necrosis of the proximal part of the scaphoid in adolescents. J Bone Joint Surg Am 84-A:915-920, 2002
115. Ben-Amotz O, Ho C, Sammer DM: Reconstruction of scaphoid nonunion and total scaphoid avascular necrosis in a pediatric patient: A case report. Hand (N Y) 10:477-481, 2015
116. Braga-Silva J, Peruchi FM, Moschen GM, et al: A comparison of the use of distal radius vascularised bone graft and non-vascularised iliac crest bone graft in the treatment of non-union of scaphoid fractures. J Hand Surg Eur Vol 33:636-640, 2008
117. Little KJ, Godfrey J, Cornwall R, Carr P, Dolan K, Balch Samora J: Increasing brace treatment for pediatric distal radius buckle fractures: Using quality improvement methodology to implement evidence-based medicine. J Pediatr Orthop. 2018 Aug 4. https://doi.org/10.1097/BPO.0000000000001239. [Epub ahead of print]