Operative Techniques in
Orthopaedics

Both Bone Forearm Fractures

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Optimal treatment of pediatric both bone forearm fractures is determined by patient age, fracture pattern, and location. As compared to their adult counterparts, pediatric patients can generally tolerate more displacement and angulation because of their increased remodeling potential. The mainstay of treatment for these injuries continues to be closed reduction and casting. However, operative fixation has increased significantly over the past decade. Currently, both flexible intramedullary nailing and plate fixation are acceptable options in this population. Flexible intramedullary nailing has the advantage of decreased surgical dissection and preservation of local biology, as well as decreased operative times; however, this treatment option may necessitate a return to the operating room for hardware removal. Open reduction and internal fixation with plates and screws may more accurately restore bony anatomy, with the potential to retain the implants. However, the optimal method of fixation has not been established and outcomes with both techniques appear to produce satisfactory results in a majority of patients. The purpose of this review is to provide an overview of the treatment options for these common pediatric and adolescent injuries.
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Introduction

Diaphyseal forearm fractures, commonly referred to as both bone forearm fractures (BBFF), are among the most commonly treated injuries in children and adolescents, representing 5% of all pediatric fractures. Despite a decrease in overall injury rate during childhood, incidence of BBFF in children has steadily increased over the past decade.[1] The mainstay of treatment in this population remains conservative management through closed means and casting. As long as angulation, rotation, and length fall within acceptable parameters, long arm casting is a successful and low-risk treatment option, and children generally do not develop significant elbow stiffness after prolonged cast immobilization. Over the past decade, however, there has been an increasing trend in operative management of these fractures.[1,2] This trend is particularly true in the adolescent population (ie, patients who are 10-16 years of age) due to less remodeling potential.

Successful treatment of BBFF results in restoration of anatomic alignment and functional range of pronosupination[3]

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The determination of treatment method and acceptable alignment are dependent upon several factors, including patient age, mechanism of injury, fracture pattern, and comorbidities, but is perhaps most largely influenced by the remodeling potential of the individual patient. In general, remodeling potential decreases with age as well as increasing distance of the fracture from the more biologically active physes of the distal radius and ulna. Current surgical treatment options include both flexible intramedullary nails (FIN) and open reduction internal fixation (ORIF) with rigid plate fixation. Both methods have advantages and disadvantages, but the literature has failed to demonstrate superiority of 1 method over another. The purpose of this article is to review the current evidence for treatment of pediatric BBFF and provide clinical recommendations for care of these common injuries.

Conservative Management

In contrast to their adult counterparts, nonoperative treatment is used for the vast majority of pediatric diaphyseal forearm fractures and is still considered to be the gold standard of care.[3,4] Multiple studies in the literature seek to provide guidelines as to how much radiographic deformity can be accepted to achieve reasonable functional outcomes, and

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Table 1 Generally Accepted Reduction Guidelines for Pediatric BBFA[5]

Patient Demographics	Angulation (Degrees)	Malrotation (Degrees)	Displacement (%)
Mid/Distal shaft fractures			
<8 yo	<15	<30	100
>8 yo (with >2 years growth remaining)	<10	<30	100
Proximal shaft fractures			
<8 yo	<10	<30	100
>8 yo	Anatomic reduction recommended		

to date, there is no consensus. Generally speaking, closed reduction is indicated in patients under 8-10 years old with angulation of greater than 10° and malrotation greater than 30°.[5] Up to 1 cm of bayonet apposition may be accepted in patients under 10 years old with satisfactory outcomes.[6] Current recommendations for what constitutes an acceptable reduction are based on the remodeling potential (ie, proximity of the fracture to the distal physis and the age of the patient; Table 1). If closed manipulation can maintain reduction within this range, functional outcomes are usually satisfactory. Several cadaveric studies have demonstrated loss of forearm motion with greater than 15-20° of residual angulation. Ultimately, however, radiographic alignment has not proven to directly correlate with clinical forearm rotation and functional outcome.[7]

Closed reduction in the pediatric population is typically performed with adequate analgesia or sedation in either the emergency department or operating room. First, the deformity is exaggerated to relax any intact periosteum and disengage the fracture fragments. Then longitudinal traction is applied and the rotational and angular deformity is reversed. Alternatively, many BBFFs are pure rotational deformities and only require derotation to achieve adequate realignment. Fluoroscopy is most commonly used during the reduction process to assess alignment; however, a recent study found that ultrasound can successfully be used in resource-limited settings.[8] Typically, after satisfactory alignment has been achieved, patients are placed into a long-arm cast or splint and immobilized at 90° of elbow flexion to limit rotational movement. Proper interosseous and 3-point molding of the cast are paramount to successful nonoperative management of these fractures (Fig. 1). Cast index, which is defined as the ratio of sagittal to coronal width of the cast, has been shown to successfully predict failure of closed treatment. A cast index >0.8 (ie, a more cylindrical cast) has been correlated with failure of closed treatment.[9] While traditional teaching prescribed to the "rule of thumb" wherein the thumb is rotated toward the apex of deformity to dictate the optimal position of forearm rotation, more recent evidence suggests that forearm position has no impact on residual angulation at the time of union.[10] Patients who have undergone reduction should be seen at weekly intervals for the first several weeks to monitor for any loss of reduction. At that point, as long as there is sufficient evidence of bony healing, patients may be transitioned to a short-arm cast and are generally maintained in this cast until 6 weeks post injury. At this point, some authors advocate for a transition to a removable splint due to the risk of refracture. Refracture occurs in approximately 4%-7% of patients within the first year after a BBFA fracture, and most commonly occurs when there is incomplete healing at the time of cast removal.[11] Patients and families are counseled to use caution and limit high-impact activities during this period.

Failure of nonoperative treatment of BBFF is rare, with 90% of these injuries being amenable to closed reduction and casting.[3,12] Loss of reduction may occur in 5%-25% of these patients and usually occurs within the first few weeks following closed reduction. In a review of 282 patients

Figure 1 A 7-year-old patient with both bone forearm fracture treated nonoperatively in a cast. She had full forearm rotation at her last follow-up visit.

treated with closed reduction and casting, Bowman et al found that most failures were likely to present within the first 3 weeks in children 10 years of age or older with proximal-third radius fractures and ulnar angulation of less than 15°.[4] This finding is consistent with earlier data that suggested older age, and greater initial angulation are predictors of early failure.[13,14] Franklin et al found that patients who were ultimately converted to open treatment were more likely to be older, have less angulation in the coronal, have a more proximal ulnar fracture, and have a more translated or shortened radius fractures.[15] In addition, obesity has been identified as an important risk factor for failure of nonsurgical management of BBFF in children. Several recent studies have demonstrated that patients with high BMI are more likely to lose reduction, require reduction in the operating room and have more follow-up appointments with greater radiation exposure.[16,17] Thus, providers should have a low threshold to employ surgical fixation techniques in these patients.

Operative Fixation

Operative treatment is warranted in patients with unacceptable alignment/loss of reduction following closed methods of treatment, nonunion, most open fractures, displaced floating elbow injuries, or those associated with severe soft tissue injury and refracture.[12] While the exact role of surgical management of pediatric BBFFs remains under debate, there have been several studies demonstrating a recent trend toward operative fixation of these injuries.[2,18]

Especially in the adolescent population (ie, children older than 8-10 years old), the limits of acceptable displacement become more stringent and the likelihood of surgical intervention increases[13,19] Currently, there are 2 commonly employed methods of surgical fixation: flexible intramedullary nailing and ORIF with rigid plating or hybrid fixation.

Flexible Intramedullary Nailing

The use of FIN by Metaizeau from Nancy, France, changed the trend of addressing long bone fractures. Proponents of this surgical technique cite preservation of local biology at the fracture site due to less surgical dissection, thus promoting the robust and expedient bony healing often seen in children.[18] Currently, flexible nails are available in both stainless steel and titanium.

Preoperative planning for FIN first involves appropriate selection of nail diameter. Commonly used flexible nail sizes range from 1.5 to 3 mm. Selection is dependent upon the diameter of the medullary canal, by measuring the narrowest canal diameter of the radius (usually midshaft) and ulna (usually distal third) on preoperative radiographs. This may then be confirmed and length is estimated by placing a nail overlying the skin of the affected forearm and using fluoroscopy to confirm appropriate size selection, with the understanding that there may be errors due to inaccuracies caused by X-ray magnification. Nails are then contoured with the maximum curvature at the level of the fracture such that it will restore appropriate radial bow.

FIN is typically introduced into the radius in the distal metaphysis via 1 of 2 physeal-sparing approaches to the distal radius. The most widely used entry site is obtained via the floor of the first dorsal compartment of the wrist (ie, the radial approach). While this approach risks a sensory neurapraxia of the superficial radial nerve, most report the return of sensation after a few weeks to months. When inserting the nail, it is prudent to protect the nerve by using a mini-open approach. Alternatively, the radius may be entered at the base of Lister's tubercle in the interval between the second and third dorsal compartments (ie, the dorsal approach). However, this dorsal approach carries a risk of extensor pollicis longus rupture, which may occur during nail insertion or may be attributed to repetitive gliding of the tendon past the tip of the nail.[20] Thus, multiple authors have advocated for the initially recommended radial approach.[21] Ulnar FIN are introduced through the proximal ulnar metaphysis and is achieved via an anconeus starting point, just posterolateral to the ridge of the olecranon. Alternatively, the tip of the olecranon may be used as a starting point, especially if hardware removal will be considered as it is a more straightforward trajectory.

FIN is passed to within 1 cm of the far physis to achieve maximal stability. Implants are then typically cut beneath the skin, being sure to leave them proud enough to facilitate later removal. In younger children, stout Steinman pins may be used for intramedullary fixation and they may be bent and cut outside the skin to allow for removal in the office after bony union. Although this second option obviates the need for a second surgical procedure to remove the nails, the theoretical risk of increased deep infection makes this a less appealing option to most surgeons. If implants are left beneath the skin, it is recommended that they be removed 6-12 months after the index procedure.

The reported range of complications of FIN ranges from 12% to 21%.[12,22,23] Complications include neurologic deficits, delayed union,[24] nonunion, compartment syndrome,[22,25] extensor pollicis longus tendon rupture,[21,26,27] and infection. Additionally, some consider the second surgery necessary to remove the implants a disadvantage of this surgical technique. The rate of complications increases in older patients[12] Conversion from closed to open reduction may be required in approximately 30% of cases, with single bone fractures being more likely to require open reduction.[28] Regarding compartment syndrome, patients with longer operative times and increased use of fluoroscopy have been found to have increased risk. Generally, surgeons are advised to attempt no more than 3 closed reduction maneuvers before converting to open reduction.[29,30]

Plate and Screw Fixation

ORIF with plates and screws remains a commonly used surgical option in the pediatric population and may provide several advantages, including maximal ability to obtain an

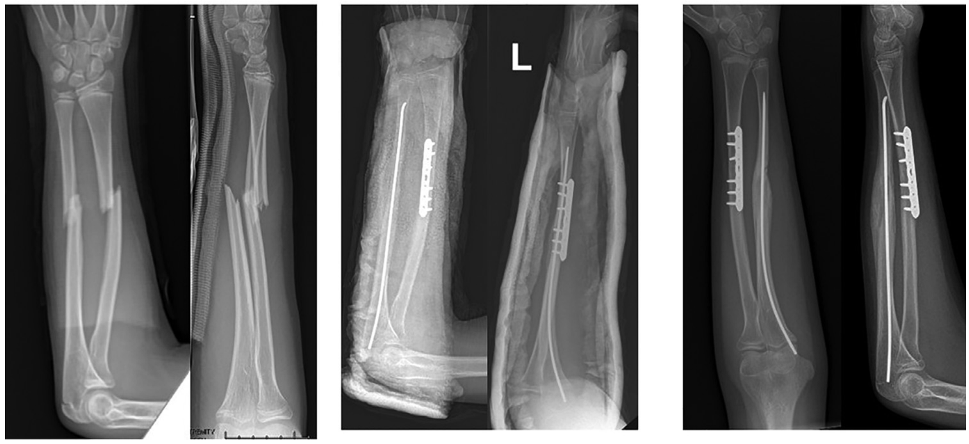

Figure 2 A 14-year-old patient with type I open both bone forearm fracture treated with hybrid fixation. He underwent removal of the nail 7 months after his initial surgery with retention of the radius plate.

anatomic reduction and restore normal radial bow, which is thought to be critical for regaining forearm rotation. In addition, the mechanical stability of the construct may permit early range of motion, which may be important especially in an adolescent population who are more prone to elbow stiffness with prolonged immobilization. Disadvantages of this technique include more extensive dissection, slower rates of bony union, and cosmetically unappealing scars.[31] Although exact indications for ORIF are still debated, many authors advocate for plate fixation in older adolescents with less remodeling potential, in the setting of significant comminution, after refracture, or with loss of reduction after attempt at conservative treatment as callous formation may prevent easy passage of flexible nails (Fig. 3).

Compression plating with 6 cortices on either side of the fracture remains the standard of care. Choice of fixation is based on the size of the bone, location, and pattern of the fracture. Commonly used implants include 3.5- and 2.7-mm dynamic compression plates, and the plate should not be wider than the bone. Separate approaches are used for the radius and the ulna to minimize the risk of synostosis. The anterior (volar) approach of Henry is commonly used for distal and middle third radial shaft fractures while the posterior (dorsal) approach of Thompson is advocated for proximal-third radius fractures, with care being taken to protect the posterior interosseous nerve. The ulna may be exposed through a subcutaneous approach and the plate may be fixed to the subcutaneous, volar, or dorsal surface of the bone. The order of fixation is variable; typically the less comminuted bone is fixed first so as to achieve the most precise restoration of length and rotation.

The need for hardware removal after ORIF remains controversial. Some advocates for removal of plate and screws after bony healing cite risk of refracture at the stress riser created by the end of the plate bony overgrowth, inflammatory/immunologic reactions to metallic implants,[32,33] and decreased bone density due to stress shielding. Plates may need to be removed due to irritation or pain at the site of the implant, which most commonly occurs at the ulna due to its subcutaneous location. Prevalence of complications following forearm plate removal in the literature ranges from 7% to 42%.[33,34] When plate removal is elected, residual screw holes increase the risk of refracture and young patients must be counseled on activity modification in the immediate postoperative period. Advocates of hardware retention cite a relatively low risk of refracture, approximately 7% risk of implant-related fracture as compared to 85% implant survival.[35,36] Thus, these authors conclude that implant removal should be at the discretion of patient, parents, and surgeon.

Open Both Bone Forearm Fractures

Traditionally, all open BBFF were treated operatively with urgent irrigation debridement and surgical fixation. However, recent literature has challenged this dogma by calling into question the role of operative intervention in type I BBFF fractures. One treatment protocol involved irrigation and debridement in the emergency department followed by 24 hours of intravenous antibiotic administration in the inpatient hospital setting and reported a 2.5% infection rate. They treated a total of 40 open fractures, including 8 tibia fractures, 18 diaphyseal forearm fractures, and 14 distal radius and ulna fractures.[37] In the most recent retrospective review of 40 pediatric forearm and tibia type I open fractures treated nonoperatively, Bazzi et al[38] showed that there were no infections and only 1 delayed union. These studies suggest that nonoperative treatment of type I open fractures in a pediatric population may be safe and have little risk of infection. While definitive conclusions from this small sample size are difficult to interpret, randomized trials of operative vs nonoperative treatment are ongoing.

Single Bone and Hybrid Fixation

Whether using FIN or ORIF with plate fixation, several authors have questioned whether dual bone fixation is

Figure 3 A 13-year-old female who previously treated with single-bone radial FIN who refractured and bent through the nail 6 months after initial fixation. She underwent revision open reduction internal fixation with plate and screws.

necessary. Some advocate for dual bone fixation as there may be an increased risk of redisplacement[39] with only single bone fixation. However, several other authors report adequate fixation in many cases.[40-42] For many surgeons, the indications for single-bone fixation are consistent with those outlined by Flynn and Waters[40]; namely, single-bone fixation is first achieved, followed by an attempt to correct malrotation and displacement of the uninstrumented bone. If an acceptable, stable reduction is able to be achieved after manipulation, single-bone fixation is considered to be sufficient, and a well-molded cast is then placed (Fig. 2). Overall, single bone radius fixation is not recommended in older patients or in cases of open fractures. In contrast, hybrid fixation using FIN of the radius and plate fixation of the ulna has been found to have satisfactory results in adolescent patients. Benefits include decreased operative and fluoroscopic time and decreased length of postoperative immobilization.[43,44] Overall, this may be considered as an alternative treatment in adolescent patients.

Comparison of Outcomes Between Flexible Nails and Plate Fixation

As summarized by several systematic reviews, current literature has not established superiority of 1 surgical method over the other for operative treatment of BBFF.[45,46] To date, there are no published randomized controlled trials of FIN vs plate trials in the pediatric population. However, individual retrospective studies have reported some notable differences worthy of discussion. Shah et al[47] looked at 61 BBFF in adolescent patients and reported more complications with ORIF (30%) as compared to IMN (20%). While several studies have found that ORIF more appropriately restores location radial bow, none have found this to have a significant impact on forearm rotation[47,48] Flynn et al[12] examined the results of FIN in both younger and older children and found that although 87% of their children younger than 10 years had an excellent outcome, only 70% had an excellent outcome older than 10 years. From a cosmetic standpoint, FIN is the most aesthetically appealing choice in studies that measured this outcome parameter.[31] Overall, studies have not found significant differences in overall complication rates or outcomes. Therefore, treatment is best decided on an individual patient basis.

Conclusions

Nonoperative management with closed reduction and casting is still the gold standard of treatment for the majority of pediatric BBFF, especially in children less than 10 years old. However, in older children with less remodeling potential, the decision to surgically intervene is on the rise. Both flexible intramedullary nailing and ORIF with plate fixation are appropriate treatment options. FIN is advantageous because of less soft tissue disruption and decreased surgical times, but surgeons must be aware of the slightly increased rate of nonunion in older patients as well as the need for hardware removal after bony union. ORIF is an attractive option because of the ability for a more accurate anatomic reduction; however, this technique is associated with longer operative times, more soft tissue dissection and more controversy about whether or not to remove implants after healing. In general, surgeons should consider ORIF in cases of severe comminution or bone loss while FIN is usually preferred for younger patients in whom closed reduction is not satisfactory. While current literature shows generally favorable outcomes regardless of which surgical method is used, surgeons should be familiar with the subtleties of each technique, as well as possible complications, in order to best ensure optimal outcomes for individual patients.

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