Risk Factors for Open Reduction in Operatively Treated Pediatric Both-Bone Forearm Fractures

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ABSTRACT

BACKGROUND Forearm fractures are a common pediatric injury. Both bone forearm fractures (BBFFs) can usually be treated non-operatively but may require hardware implantation with or without open reduction. Previously reported rates of open reduction in operatively managed BBFFs range from 8% to 72%. Little data exist to help surgeons predict which BBFFs will require open reduction. The purpose of our study was to identify factors associated with the need to perform an open reduction during operative treatment of BBFFs.

METHODS We analyzed data of all patients who presented to a Level I pediatric trauma center with radiographically confirmed diaphyseal BBFFs treated with intramedullary (IM) fixation between 2008 and 2012. Patient demographics, injury mechanism, and surgery-related data were collected. Closed reduction was first attempted in all patients who underwent open reduction. We compared those treated with closed reduction to those treated with open reduction.

RESULTS 40 patients with operatively treated BBFFs were identified. Of these, 28 were male, and 12 were female. The mean age at injury was 10.83 (±3.02) years. 57.5% (n=23) underwent closed reduction and IM fixation of the ulna (13.0%, n=3), radius (26.1%, n=6), or both bones (60.9%, n=14). 42.5% (n=17) were treated with open reduction and IM fixation of either the radius (11.8%, n= 2) or both bones (88.2%, n= 15). There were no statistically significant associations between the need to perform an open reduction and patient age, mechanism of injury, time to operating room, ulnar or radial fracture location, angulation, translation, or shortening; however, males were more likely than females to require an open reduction (88.89% vs. 11.11%, p=0.030).

CONCLUSION At our institution, 42.5% of patients with BBFFs treated with IM fixation required open reduction. Initial fracture displacement does not help predict the need for an open reduction at the time of surgery. Patients who are male are significantly more likely to require an open reduction. The findings of this study may assist in pre-operative planning and patient counseling in treatment of both-bone forearm fractures.

LEVEL OF EVIDENCE Therapeutic Level IV, Case Series

KEYWORDS Both bone forearm fracture, open reduction, BBFF, pediatric forearm

Forearm fractures are among the most common orthopedic injuries in the pediatric population with significantly increased incidence in recent years.[1,2] Of these, both bone forearm fractures (BBFFs) can be particularly problematic biomechanically and must heal in acceptable alignment to maintain full functionality of the upper extremity. Stable reduction to maintain acceptable alignment is especially important in older children who are the most prone to malunion due to limited remodeling capability.[3,4,5]

BBFFs can be managed with closed reduction and cast immobilization or with closed or open reduction and internal fixation. Previous studies have confirmed the efficacy of each technique in treating these injuries.[6,7,8] Closed reduction and immobilization is the preferred method when possible, as it avoids many of the inherent risks of an incision and hardware implantation.[9,10] Acceptable angulation before surgical intervention varies with age and fracture location. In children with at least 2 years of growth remaining, greater angulation after closed reduction is acceptable. For these patients, the upper limits in the coronal and sagittal planes include 20 degrees in the distal third, 15 degrees in the middle third, and 10 degrees in the proximal third.[11] Adolescents nearing skeletal maturity are usually treated according to adult criteria due to their limited remodeling capability.[12]

Recently, operative internal fixation has become increasingly common in these types of injuries.[2,9,13,14] Intramedullary nails or plate-and-screw constructs are options for fracture fixation; both methods of stabilization have been shown to be similarly effective.[14,15] Intramedullary nails are the more popular choice given their ease of use, short operative time, and minimal surgical dissection.[6] Sinikumpu et al. found a 20% increase in the use of internal stabilization by elastic stable intramedullary nails (ESINs) from 1998-2000 to 2007-2009.[2] Current consensus is that cases with malreduction after closed manipulation, open fractures, compartment syndrome, and ipsilateral humerus fractures causing a "floating elbow" should be operatively managed with internal fixation.[16]

When intramedullary fixation is chosen to treat a fracture, the reduction can be achieved in a closed or open manner. While the least invasive treatment is preferred whenever possible, open reduction is still required to treat some pediatric BBFFs. Reported rates of open reduction have been highly variable in the last twenty years, with a range of 8-72%.[13,17-20] Despite these rates, little data exist to help physicians predict which cases will require open reduction. Zionts et al. noted that age greater than 10 years predisposes to failure of closed reduction.[6] Sinikumpu et al. found that displacement greater than 10 millimeters (mm) in the radius or ulna and male sex predicted need for invasive operative treatment with implanted hardware but did not describe these features as independent predictors for open reduction.[21]

The purpose of our study is to identify risk factors that contribute to the need to perform an open reduction during operative treatment of BBFFs.

METHODS

We performed an IRB-approved, five-year retrospective review of all patients who presented to a Level I pediatric trauma center between January 2008 and December 2012 with a diaphyseal BBFF treated by intramedullary (IM) fixation. Participants were selected by a comprehensive review of the department's surgical list, billing codes, and electronic medical records. Patients with incomplete records, missing injury radiographs, fracture-dislocation variants, open fractures, and plastic deformations or incomplete fractures of either bone were excluded from our study. Closed reduction with immobilization was attempted first in all patients. The decision to proceed with operative fixation was not standardized and was at the discretion of each of the ten attending surgeons at our institution during this time.

Demographic and historical data were collected by chart review in the electronic medical record. This included patient age, height, weight, body mass index (BMI), re-fracture, and relevant medical history. Details about the injury, including mechanism and timing, were also recorded. Additionally, physical exam documentation was reviewed for any signs of open fracture or neurovascular compromise. All patients underwent closed reduction attempts prior to going to the operating room.

Anteroposterior (AP) and lateral radiographs were available for all patients. All measurements were made using the standard image-viewing software in the electronic medical record by medical students with random checks of the measurements by an orthopaedic surgery attending. Measurements included fracture location in thirds (distal, middle, proximal), fracture angulation in each plane, horizontal translation, and vertical shortening. Separate measurements were recorded for the radius and the ulna.

Surgical data were collected through review of full operative reports in the electronic medical record. Treatment was classified as an open reduction if an incision was made over the fracture site in order to directly manipulate the bone. Closed reduction was defined as manipulation of the entire forearm without manipulating the fractured bone through an additional incision at the fracture site. Data were recorded for both the radius and the ulna in every case. Isolated open reduction of the radius or ulna was performed in cases where adequate closed reduction of the second bone could be achieved. In cases where hardware was used for both bones, the sequence of fixation was recorded.

Continuous variables are summarized as median with minimum and maximum values and were compared via the Mann Whitney U and Wilcoxon test. Normality assumption was tested using the Shapiro-Wilk test. The categorical variables are summarized as counts with corresponding percentages, and were compared via the Pearson Chi-square or Fisher's exact test. Statistical significance was set at $p \leq 0.05$. All analysis was conducted using SPSS software version 22.0.

RESULTS

We identified 40 patients, 28 males (70%) and 12 females (30%), with BBFFs that were treated with intramedullary fixation. They were all skeletally immature with open distal radial physes in the forearm radiographs reviewed. The mean age at injury was 10.83 (±3.02) years. The most common mechanism of injury was fall (18/40; 45%). 12.5% (n=5) patients presented with a re-fracture, meaning they had a prior both bone forearm fracture with new displacement and angulation after repeated trauma **(Table 1)**. The average time to the operating room since injury was 3.25 days (range: 0-17 days) and the median time was 1 day. Overall, 67.5% (n=27) patients received surgical intervention within 48 hours **(Table 2)**.

Fourteen patients were treated with closed reduction and intramedullary fixation of both bones. Seventeen patients (42.5%) required open reduction of at least one bone. Isolated open reduction of the radius was most common (10/17; 58.82%), followed by open reduction of both bones (5/17; 29.41%), and isolated open reduction of the ulna (2/17; 11.76%). Of the 40 operatively treated BBFFs, 29 were treated with intramedullary fixation of both bones. In some cases, reduction of both bones was adequate after fixation of a single bone; this strategy was utilized in 11 patients, with isolated fixation of the radius in 8 patients and the ulna in 3 patients **(Table 2)**.

Males (15/28; 53.57%) were more likely to require an open reduction compared to females (2/12; 16.67%) (p=0.03). There were no statistically significant associations between the need to perform an open reduction and patient age, mechanism of injury, time to operating room, ulna or radial fracture location, angulation, translation, or shortening **(Tables 1 and 2)**.

DISCUSSION

At our institution, 42.5% of the BBFFs treated with IM fixation required open reduction of at least one forearm bone. In the literature, there is a large amount of variability on the need for open reduction of at least one bone in closed BBFAs. Several series note much lower rates of open reduction, ranging from 8% to 17%, while others report a much higher rate of 51%.[13, 17-20] Our finding of 42.5% is on the upper end of previously reported rates.

We found that males were significantly more likely to require an open reduction. Males may be more likely to require open reduction due to their lean muscle mass, which is usually greater than that of females at similar ages.[22] This difference becomes more pronounced after puberty but is present throughout childhood.[22] The muscle likely increases soft tissue resistance to achieving reduction, even in a paralyzed state during surgery, presumably both by physically impeding bony alignment and offering baseline static resistance. Ryan et al. reinforced this concept by previously demonstrating that male children with forearm fractures were more likely to require reduction maneuvers before immobilization than their female counterparts, though this was confounded by the fact that males tended to sustain higher-energy trauma in their series.[23]

The increased rate of open reduction at our institution over some previously reported rates could signify a shift toward more aggressive treatment of these injuries in recent years. Reducing more difficult fracture patterns in the operating room may make open reduction more likely, especially when other small incisions are required for intramedullary fixation. Blackman et al. and Yuan et al. both

TABLE 1 **Demographic and Preoperative Characteristics of patients who underwent open and closed reduction.** Data are presented as median with minimum and maximum values or counts with percentages.

Variable	Overall Sample (N=40)	Closed Reduction (N=23)	Open Reduction (N=17)	P Value
Age (yrs)	11 (4-16)	11 (6-16)	12 (4-16)	0.912
Height (cm)	144.60 (102.9-174.0)	143.55 (112.0-174.0)	149.80 (102.90-174.0)	0.993
Weight (kg)	44.20 (14.50-90.40)	44.70 (19.50-63.60)	41.40 (14.50-90.40)	0.988
Body Mass Index (kg/cm²)	18.70 (13.66-32.81)	19.93 (13.66-28.50)	18.59 (13.69-32.81)	0.293
Sex				***0.030**
Female	12 (30.0)	10 (43.5)	2 (11.8)	
Male	28 (70.0)	13 (56.5)	15 (88.2)	
Mechanism of Injury				0.173
Fall	18 (45)	8 (34.8)	10 (58.8)	
Football	4 (10.0)	2 (8.7)	2 (11.8)	
Trampoline	9 (22.5)	8 (34.8)	1 (5.9)	
Other	9 (22.5)	5 (21.7)	4 (23.5)	
Refracture				1.000
Yes	5 (12.5)	3 (13.0)	2 (11.8)	
No	35 (87.5)	20 (87.0)	15 (88.2)	

*Statistically significant at p<0.05

TABLE 2 **Characteristics of patients who underwent open and closed reduction based on initial injury radiographs and intraoperative technique.** Data are presented as median with minimum and maximum values or counts with percentages.

Variable	Overall Sample (N=40)	Closed Reduction (N=23)	Open Reduction (N=17)	P Value
Radius Fx Angle on AP	10 (0-62)	11 (0-62)	9 (0-23)	0.324
Ulna Fx Angle on AP	7.5 (0-65)	12 (0-65)	7 (0-15)	0.146
Radius Shortening (mm)	0 (0-28)	0 (0-28)	2.50 (0-12)	0.630
Ulna Shortening (mm)	0 (0-16)	0 (0-16)	0 (0-11)	0.448
Radius Fx Angle on Lateral	14 (2-97)	18 (2-97)	11 (2-76)	0.135
Ulna Fx Angle on Lateral	17.50 (0-96)	20 (0-96)	12 (1-67)	0.538
Time to OR since Injury (days)	1 (0-17)	1 (0-10)	2 (1-17)	0.138
Time to OR since Admission				0.746
≤48 hours	27 (67.5)	16 (69.6)	11 (64.7)	
>48 hours	13 (32.5)	7 (30.4)	6 (35.3)	
Bone Fixation				0.121
Both	29 (72.5)	14 (60.6)	15 (88.2)	
Radius	8 (20.0)	6 (26.1)	2 (11.8)	
Ulna	3 (7.5)	3 (13.0)	0 (0.0)	
1st Bone Reduced/Fixed				0.131
Radius	22 (55.0)	15 (65.2)	7 (41.2)	
Ulna	18 (45.0)	8 (34.8)	10 (58.8)	
Radius Fx Location				0.672
Distal	7 (17.5)	5 (21.7)	2 (11.8)	
Mid	23 (57.5)	13 (56.5)	10 (58.8)	
Proximal	10 (25.0)	5 (21.7)	5 (29.4)	
Ulna Fx Location				0.676
Distal	12 (30.0)	7 (30.4)	5 (29.4)	
Mid	27 (67.5)	15 (65.2)	12 (70.6)	
Proximal	1 (2.5)	1 (4.3)	0 (0.0)	
Apex on AP				0.073
Dorsal	1 (2.7)	1 (4.8)	0 (0.0)	
Radial	11 (29.7)	9 (42.9)	2 (11.8)	
Ulnar	25 (67.6)	11 (52.4)	14 (82.4)	
Apex on Lateral XR				0.734
Dorsal	11 (28.2)	6 (26.1)	5 (29.4)	
Volar	28 (71.8)	17 (73.9)	11 (68.8)	
Radius Fixation Type				0.492
ESIN	36 (94.7)	19 (90.5)	17 (100.0)	
IM Steinmann	2 (5.3)	2 (9.5)	0 (0.0)	
Plate	0 (0.0)	0 (0.0)	0 (0.0)	
Ulna Fixation Type				0.101
ESIN	27 (87.1)	12 (75.0)	15 (100.0)	
IM Steinmann	4 (12.9)	4 (25.0)	0 (0.0)	

Anteroposterior = AP, Operating Room= OR, Fracture = Fx, Intramedullary = IM, Elastic Stable Intramedullary Nail = ESIN independently reported the increased risk of compartment syndrome with longer operative times in BBFF treatment. They each attribute the risk of compartment syndrome to a greater degree of soft tissue trauma from repeated attempts at reduction and IM nail passage.[17, 24] In response, some institutions have now implemented practice guidelines suggesting a maximum of three intramedullary nail passage attempts to mitigate risk of compartment syndrome.[25] As a result, many pediatric orthopedic surgeons may now have a lower threshold to open reduce these fractures.

For the surgeon, knowledge of the association of open reduction with male gender can enhance operative planning and surgical efficiency when caring for these patients. By knowing that males may be predisposed to the need for an additional incision, the surgeon can better explain the operative procedure to a family. This understanding enhances informed consent and tempers parental expectations, most specifically in regards to operative time, potential complications, and scar formation.

There are several limitations inherent to our study. Our small study population (n=40) limits the statistical power and increases the risk of random error. Since all data were collected from the same institution, institutional practice bias may account for the unique findings in our study. The retrospective nature of the study limits our data collection, forcing a reliance on electronic records and operative reports. Despite careful interpretation of these resources, it is possible that the documentation and actual clinical events differed slightly.

There are several directions for future research efforts on this topic. Biomechanical studies of forearm fracture reduction could elucidate the underlying reasons for more difficult closed reductions in males. A prospective multi-institutional study would offer a larger sample size with less institutional practice bias. More information about the surgical cases, such as time before converting to open reduction and long-term outcomes comparisons of the study groups, could prove beneficial in prospective trials. Finally, decision-making analysis may offer insight into the modern orthopaedist's approach to operative management of BBFFs.

In summary, BBFFs are more frequently being treated with hardware stabilization. At our institution, nearly half of operatively managed BBFFs required an open reduction, and males were significantly more likely to require an additional incision to pass the IM nail. The findings of this study may assist in pre-operative planning and patient counseling while treating BBFFs.

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