Eleven Years Experience in the Operative Management of Pediatric Forearm Fractures

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**Background:** There has been a trend toward operative management of pediatric diaphyseal forearm fractures (DFFx). We studied our experience with surgical management of these injuries to assess indications, frequency, outcome, and complications.

**Methods:** One hundred forty-four consecutive children had surgical management of 149 DFFx over 11 years at our Level 1 pediatric trauma center. A chart/radiographic review established perioperative events, intraoperative findings, time-to-union, range-of-motion, and complications. We developed the Children's Hospital of Philadelphia Forearm Fracture Fixation Outcome Classification to assess postoperative outcomes.

**Results:** Over 11 years, we treated 2297 DFFx; 155 of 2297 (6.7%) had surgical management. Six were lost to follow-up and excluded. A 7-fold increase in operative management was observed over the study period [2 of 143 (1.4%) vs. 28 of 270 (10.4%), *P < 0.001]. One hundred and three of 149 (69.1%) were treated with intramedullary nailing (IMN); 44 of 149 (29.5%) with plates; and 2 of 149 (1.3%) had combined plate/nail fixation. Thirty of 103 (29.1%) had the fracture site opened to pass the IMN; in 23 cases, open fractures were exploited to assist nail passage. When managed with IMN, open fracture sites showed slowed healing: union was 8.6 weeks for those opened intraoperatively and 6.9 weeks for those remaining closed (*P < 0.001). Fractures opened secondary to injury achieved union at 9.75 weeks which was significantly longer than those opened intraoperatively (8.6 wk, *P = 0.04) and those remaining closed (6.9 wk, *P = 0.001). Compartment syndrome occurred in 6.7% (2 of 30) treated with IMN within 24 hours of injury versus 0 of 73 treated later (*P = 0.026). Delayed union after IMN occurred in 6 children 10 years of age versus none less than 10 years of age. Poor/fair outcome of IMN increased with age [6 of 47 (13%) ≤10 y of age, vs. 17 of 56 (30%) > 10 y of age, *P = 0.03]. Overall complication rate for IMN was 14.6% (15 of 103).

**Conclusions:** Our center has operatively managed DFFx with increased frequency over the past decade. IMN had a complication rate of 14.6% and was frequently not “minimally invasive.” An open fracture site delayed healing. Compartment syndrome was more frequent when IMN was used the day of injury and older children had poorer outcomes and higher rates of delayed union.

**Level of Evidence:** Level III, Retrospective Comparative Study.

**Key Words:** pediatric, forearm fractures, operative treatment, nailing, plating

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**Diaphyseal forearm fractures** are common injuries among children, comprising 3% to 6% of all pediatric fractures.1–3 Closed reduction and cast immobilization remain the current gold standard for treating most of these fractures, as studies show that up to 85% of patients with displaced forearm fractures achieve satisfactory results from closed reduction.4,5 In general, most investigators suggest that operative treatment of pediatric forearm fractures should be reserved for patients in whom satisfactory alignment cannot be achieved through closed means.

The precise role of surgical stabilization in the management of pediatric fractures is controversial.6 Despite favorable results with conservative management in the majority of cases, there has been a rising trend toward surgical management for a larger percentage of diaphyseal forearm fractures. A recent observational study showed an increase in the rate of intramedullary (IM) nailing of forearm shaft fractures from 1.8% to 22% as an alternative to closed reduction and cast immobilization over a 10-year period.7 Further, Schmittenbecher7 has shown that surgical management of diaphyseal forearm fractures at their institution has increased from 1% between 1976 and 1985 to 40.4% between 1998 and 2000. This trend has largely been driven by technologic advances, sociologic changes, liability concerns, and perhaps even medical economics.

With the trend toward operative management of pediatric diaphyseal forearm fractures, IM nailing of pediatric forearm fractures has been rapidly adopted as a “minimally invasive” treatment compared with plate fixation (the standard mode of therapy for similar adult fractures). Good results have been reported in several series, leading to widespread enthusiasm of IM fixation.8,9 We and others, however, have observed several shortcomings of IM fixation, including delayed union, the
need to frequently expose the fracture site, compartment syndrome (CS), and wound problems. To investigate these concerns, we studied an 11-year period of operative experience with pediatric diaphyseal forearm fractures. The purpose of this study was to review our long-term surgical experience with IM nailing to better understand the risks and complications associated with this procedure.

METHODS

Patient Selection and Data Collection

After approval from the Institutional Review Board at our institution, we performed a retrospective review of all patients treated for diaphyseal forearm fractures between January 1997 and January 2008. A preliminary search of current procedural terminology codes for open (operative) and closed treatment of diaphyseal forearm fractures in our computerized database identified the total number of consecutive patients treated within this time frame. A comprehensive review of all patients with diaphyseal forearm fractures stabilized with IM or plate fixation of the radius, ulna, or both was subsequently performed to reveal the overall rate of operative fixation for these fractures. Given our interest in those patients who required operative intervention, we reviewed the clinic notes, operative summaries, and radiographic films for this selected group of patients to obtain the following information: patient age, sex, date of injury, date of surgery, fracture status (open vs. closed), fracture location (proximal 1/3 vs. middle 1/3 vs. distal 1/3), fracture pattern (transverse or oblique, radius and ulna, radius only, and ulna only), indications for surgery (open fracture, unacceptable alignment, nonunion, and refracture of previously treated fracture), choice of implant, duration of follow-up, time to radiographic union, final range of motion (supination and pronation), and postoperative complications. Delayed union was defined as inadequate consolidation at 90 days as described by Schmittebecher et al.6 Clinical outcome was determined using a straightforward outcome tool developed by the investigators and assessed at the final follow-up appointment. An excellent, fair, or poor classification was assigned using the Children’s Hospital of Philadelphia Forearm Fracture Fixation Outcome Classification (Table 1). We excluded any patient with an elbow or wrist fracture at the junction of the diaphysis and metaphysis, as these fractures have a different clinical prognosis. In addition, any patient with a pathologic fracture secondary to tumor or bone metabolic disease, radial head fracture, and Monteggia or Galeazzi fractures were not included in this study.

Statistical Analysis

Statistical analysis was performed using the Student t test to detect significant differences in the mean time to fracture union for fractures that had to be opened at the fracture site to facilitate passage of the IM nail versus those fractures that were treated with closed reduction and percutaneous IM fixation. Using χ2 analysis, we compared the following: (1) the change in rate of operative management from the first to last year of the study. (2) The rate of postoperative forearm CS for those patients who underwent IM nail fixation within 24 hours of the initial injury compared with those patients who received IM stabilization more than 24 hours after their injury. (3) The functional outcome after treatment with IM nailing for patients of 10 years of age and younger with those of greater than 10 years of age. Statistical significance was set at the α = 0.05 level.

RESULTS

A total of 2297 diaphyseal forearm fractures were treated at our institution by 10 attending surgeons between January 1997 and January 2008. During this period, 6.7% (155 of 2297) of fractures required operative management in 150 patients (112 males and 38 females). Six of these patients (2 female and 4 male) were lost to follow-up before union and therefore excluded from this study. Out of 149 fractures, we observed a 7-fold increase in operative management between the first and last year of the study (2 of 143, 1.4% vs. 28 of 270, 10.4%, P < 0.001) (Fig. 1). The mean age of patients treated operatively was 11.2 years (range: 3 to 17 y) and mean follow-up was 5.1 months (range: 1 to 26 mo). Of the 149 fractures that required surgical stabilization, 69.1% (103 of 149) underwent IM fixation alone. Of these, titanium elastic nails were used 68% of the time whereas smooth Kirschner wires were used for 32% of the cases. The average age of patients treated with IM fixation was 10.6 years (range: 3 to 16 y). About 29.5% (44 of 149) of fractures were operatively managed using plate fixation. The mean age of patients treated in this manner was slightly older (mean age 12.7 y, range: 7 to 17 y) relative to those patients who underwent IM fixation. When examining the trend of IM fixation and plating according to age groups, we found only 20.3% of fractures were treated with standard plating in patients aged 2 to 10 years (47 IM nail, 12 plates), whereas 36.4% of fractures were plated in patients aged 11 to 16 years (56 IM nail, 32 plates). Only 1.3% of fractures (2 of 149) were treated with combined IM nail/plate fixation (age 8 and 14 y). A total of 59.7% (89 of 149) of fractures treated operatively

| TABLE 1. Forearm Fracture Fixation Outcome Classification |
|----------------|-----------------------------|
| Clinical        | Outcome Score | Criteria                                      |
| Outcome Score   | Full range of motion (supination and pronation), and no postoperative complications |
| Excellent       | Minimal loss of range of motion (<30 degree of supination and/or pronation) and/or minor, resolving postoperative complication |
| Fair            | Loss of range of motion (supination and pronation) > 30 degree, and/or major postoperative complication (ie, infection, compartment syndrome, or delayed union) |
| Poor            |                                                                                       |
with either IM nails or plate-and-screws were successfully reduced using single bone fixation principles.

According to the surgeon, the most common surgical indication was unacceptable alignment following attempts at closed reduction in 69.1% (103 of 149) of cases (Table 2). When IM fixation was the preferred surgical technique, 29.1% (30 of 103) of fractures required an additional incision at the fracture site to facilitate passage of the IM nail. In 23 additional cases, the open fracture site was exploited to assist nail passage across the fracture. Evaluation of both the clinic notes and corresponding radiographs was subsequently performed to determine the effect of fracture site exposure on fracture healing when IM fixation was used. The mean time to fracture union was 8.6 weeks (range: 4 to 12 wk) for those fractures that were opened during IM nail passage compared with 6.9 weeks (range: 4 to 11 wk) for those fractures that did not require an additional incision ($P < 0.001$). Fractures treated with IM nailing and opened secondary to injury took 9.75 weeks (range: 6 to 16 wk) to heal which was significantly longer than those that were opened surgically (8.6 wk, $P = 0.04$) and those that remained closed (6.9 wk, $P < 0.0001$). Clinical outcomes were similar to fractures that were not opened (Table 3).

Of the 44 patients undergoing plate fixation, 26 of 44 (59%) underwent single bone fixation (19 radius and 7 ulna), whereas the remaining 16 of 44 (41%) required plates on both the radius and ulna. Union was achieved at a mean of 9.2 weeks (range: 6 to 16 wk). As seen in Figure 2, there is a slight trend toward longer times to union in older patients. Of these patients, one (1 of 44, 2.2%) developed a CS on postoperative day 1, and 11 of 44 (25%) had minor pronation/supination deficits at last follow-up.

The overall complication rate in patients undergoing IM nail fixation alone was 14.6% (15 of 103); complications included delayed union (6 cases), CS (2 cases), and infection (2 cases). There were also 3 prophylactic fasciotomies and 2 cases of tendon laceration during IM nail insertion at Lister’s tubercle. Both patients with tendon lacerations developed an inability to extend their thumb postoperatively, and at the time of IM nail removal they were found to have a ruptured extensor pollicis longus tendon in the area of Lister’s tubercle.

Delayed union was more common in patients ≥10 years of age (6 of 67) treated with IM nail fixation (Fig. 3); there were no cases of delayed union in patients younger than 10 years of age. Four of these patients required reoperation and union was achieved with compression plate fixation. One patient treated initially with plate fixation required a reoperation 6 months after surgery for implant removal secondary to infection.

The rate of forearm CS was 6.7% (2 of 30) in patients treated with IM nailing on the day of the injury; there were no cases (0 of 73) of CS in patients treated more than 24 hours after the initial injury ($P = 0.026$).

### TABLE 2. Indications for Surgical Management

<table>
<thead>
<tr>
<th>Surgical Indications</th>
<th>% of Cases (N = 149)*</th>
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<tbody>
<tr>
<td>Unacceptable alignment</td>
<td>69</td>
</tr>
<tr>
<td>Open fracture</td>
<td>22</td>
</tr>
<tr>
<td>Refracture of previous fracture</td>
<td>4</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
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*Note: Estimated to nearest whole number.

### TABLE 3. IM Fixation Outcome: Open Versus Closed Fractures

<table>
<thead>
<tr>
<th>Patient Outcome</th>
<th>Open Fracture (%)</th>
<th>Closed IM Nailing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>40 (75)</td>
<td>40 (80)</td>
</tr>
<tr>
<td>Fair/poor</td>
<td>13 (25)</td>
<td>10 (20)</td>
</tr>
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</table>

IM indicates intramedullary.
Using the aforementioned outcome tool based upon final range of motion and postoperative complications (Table 1), we assigned an outcome score of excellent, satisfactory, or poor to each patient treated with IM nailing. Of 103 patients, 77.7% (80 of 103) had excellent outcomes (Fig. 4), 14.6% (15 of 103) had fair outcomes, and 7.8% (8 of 103) had poor outcomes.

Given our particular interest in the safety and efficacy of IM nailing in young children, we divided the patients into 2 groups: (1) 2 to 10 years of age and (2) older than 10 years of age. We found that children above 10 years of age treated with IM nails had a higher rate (17 of 56, 30%) of poor or fair clinical outcomes compared with those less than 10 years old (6 of 47, 13%, \( P = 0.03 \)) (Table 4).

**DISCUSSION**

Following an international trend toward more aggressive management of pediatric fractures, orthopaedic surgeons have rapidly adopted IM nailing of pediatric diaphyseal forearm fractures as a “less invasive” procedure, relative to standard plating. In adults, plate fixation is the standard treatment for diaphyseal forearm fractures. With a greater ability to remodel, closed reduction and casting is the treatment of choice for pediatric diaphyseal forearm fractures. Generally, such nonoperative management results in a good clinical outcome.\(^{17–19}\) There are situations, however, in which operative management is beneficial to avoid repeat reductions, additional corrective surgical procedures, and functional limitations.

The treatment of diaphyseal forearm fractures is guided by studies that relate residual deformity to loss of motion. A cadaveric study by Tarr et al\(^ {20}\) demonstrated the essential relationship between structure and function, as the investigators found that fracture angulation between 5 and 10 degrees at the midshaft of the forearm can lead to pronation deficits of 10% to 83% of normal and supination deficits of 5% to 27% of normal. Given the potential failure of nonoperative management (1.5% to 31%)\(^ {21–23}\) and the importance of minimizing angular deformity to preserve normal forearm rotation, operative management of pediatric forearm fractures has become increasingly popular. There is debate as to whether so much operative management of pediatric forearm fractures is justified. A study by Daruwalla\(^ {2}\) followed the long-term clinical outcomes of 53 forearm fractures treated with closed reduction and cast immobilization. He found that although 28 patients demonstrated notable limitations of supination, pronation, or both upon clinical examination, none of these patients complained of difficulties related to forearm motion. Morrey et al\(^ {24}\) determined that the majority of daily activities can be performed with 100 degree of forearm rotation equally divided between pronation and supination. These 2 studies suggest that the residual angulation after closed reduction and casting may be well tolerated by children.

The 2 standard modes of forearm fracture fixation are IM nailing and plate fixation. The advantages of open plating include accurate anatomic alignment and early, unprotected range of motion. Plating of forearm fractures is much less frequent in children than in adults, and is generally reserved for fractures in older adolescents, comminuted fractures, and in situations where there is a need for immediate motion.\(^ {21,25–27}\) At our center, we use IM fixation approximately 70% (103 of 149) of the time. Various studies have shown that IM nailing can provide precise fracture reduction, maintains stabilization for fracture healing, results in minimal cosmetic deformity, and facilitates easy removal of implants after treatment.\(^ {8,9,11,13,28–34}\) However, documented complications of this technique include nail site infections, skin irritation at nail insertion sites, fracture displacement after implant removal, implant migration or failure (bent or broken pins), loss of reduction, refracture, nerve and tendon injury, decreased range of motion, delayed union/non-union, and CS.\(^ {4,5,9–14,35}\)

A recent study by Yuan et al\(^ {14}\) described the incidence of CS in patients undergoing IM nailing. Although the overall occurrence of CS in pediatric forearm fractures is relatively rare, the investigators did demonstrate an increased risk in patients who underwent IM nailing, concluding that multiple passes with the IM nails causes increased soft tissue injury. The investigators suggest that the fracture should be opened if the nail cannot be passed within 3 passes. This “3 pass rule” is often discussed, and has been adopted at many centers. Perhaps this is one contributing factor to the frequency that the fractures are opened. Other fractures were clearly opened because there was interposed tissue, or a satisfactory reduction could not be obtained to pass the nail.

Compared with open reduction and compression plate fixation, IM nailing is considered to be much less invasive. However, the frequency of open reduction during IM surgical stabilization in a previously closed fracture has been reported to be as high as 38% to 74.4% in the literature.\(^ {8,13,15,34,36}\) At our center, 29.1% of closed fractures required an additional incision at the fracture site to facilitate satisfactory reduction. Lascombes et al\(^ {8}\) found that the most common cause of conversion to open reduction is soft-tissue interposition. Several investigators...
note that open reduction is sometimes necessary because of delay in treatment, which can result in soft-tissue contracture, making closed reduction extremely challenging. Although the use of open reduction with a “minimally invasive procedure” such as IM nailing is perceived as a failure of the technique, some investigators believe open reduction facilitates accurate IM fixation and is much less traumatic to the fracture site than multiple reduction maneuvers. We found surgical dissection at the fracture site correlates significantly with slower fracture healing, as fractures that required additional exposure took an average of 2 weeks longer to achieve bony union. The explanation for this correlation is likely 2-fold: (1) the opening of the fracture site likely leads to delay in healing and (2) these fractures may require opening secondary to their being more severely displaced (ie, more periosteal stripping).

In those patients treated with IM nailing, the overall complication rate was 14.6%. Cullen et al found that older adolescents (mean age 13 y) treated with IM fixation demonstrated a higher complication rate, with a total of 18 complications occurring in 50% of patients. Schmittenbecher et al, in a series of 532 patients treated with IM nailing, reported 10 cases of delayed union with
an average age of 12.3 years. We found that IM fixation led to a higher rate of delayed union and poor clinical outcomes in patients of 10 years of age and older.

We are aware that there are several limitations to this study. Given the retrospective design of this study, we are limited to existing data and are unable to

FIGURE 4. X-rays of a 7-year-old male who sustained both bone forearm fracture after falling from a jungle gym. Injury films are shown (A, B). The fracture was treated with intramedullary nailing of both the radius and ulna (C, D). Union was achieved at 7 weeks and nails were removed. Final films reveal excellent healing and anatomic alignment 9 months after index surgery (E, F).

<table>
<thead>
<tr>
<th>Patient Outcome</th>
<th>Age 2-10 y (%)</th>
<th>Age 10 y (%)</th>
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</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>41 (87)</td>
<td>39 (70)</td>
</tr>
<tr>
<td>Fair/poor</td>
<td>6 (13)</td>
<td>17 (30)</td>
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</table>
control specific aspects of patient care including interval between appointments and length of follow-up. This has left us with a limited follow-up period (mean = 5.1 mo); however, in the treatment of pediatric fractures, extended follow-up is not typical. Furthermore, we were not able to base our final clinical outcome on a standardized physical examination. Instead we had to rely on existing medical records, prompting us to create our own clinical assessment (the Children’s Hospital of Philadelphia Forearm Fracture Fixation Outcome Classification) which still requires validation. A prospective study describing the operative treatment of diaphyseal forearm fractures in the pediatric population would be an improvement on our study design. Further, a similar study with a nonoperative control group would be ideal.

Over the last decade, there has been a strong trend toward the increased use of internal fixation for pediatric and Adolescent diaphyseal forearm fractures. At our Level 1 pediatric trauma center, there has been a 7-fold increase in operative management of these fractures over the past 11 years. Although the results were generally excellent (as one would expect for a fracture that was traditionally treated successfully by closed reduction and casting), we found that IM nailing often required open reduction, had a complication rate of 14.6%, and was less successful in children of 10 years of age and older. In the age of informed consent, we suggest that treating surgeons and families consider this data as they make important decisions regarding operative management of forearm fractures in children. Further, we recommend a low threshold for the use of plate fixation in older patients requiring internal fixation.

REFERENCES


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