Treatment Choice of Complete Distal Forearm Fractures in 8 to 14 Years Old Children

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Background: New surgical techniques have challenged traditional guidelines for nonsurgical treatment in pediatric and adolescent distal forearm fractures. This study was performed to compare outcomes and costs between closed reduction with percutaneous pinning (CRPP) and closed reduction with casting in the treatment of complete distal forearm fractures in children 8 to 14 years old.

Methods: A retrospective cohort study was performed of 175 displaced distal forearm fractures treated with 2 different methods in the emergency department of a children's trauma center. One hundred and fourteen children were managed using CRPP. The remaining 61 were treated with closed reduction and casting. All patients had initial follow-up radiographs. The quality of reduction and the residual angulation in both the coronal and sagittal planes were recorded. Outcomes included the angulation after reduction, residual angulation at final follow-up, radiation exposure, total immobilization time, days absent from school, total costs, and postoperative complications.

Results: The postreduction sagittal plane angulation was significantly lower in the CRPP group ($P=0.037$). While residual deformity between the groups at the 6-month final follow-up was not significantly different in either the sagittal or coronal planes ($P=0.486$, 0.726), patients in the nonoperative group received greater radiation than those in the operative group ($P<0.001$). Patients in the nonoperative group missed fewer classes and sustained lower costs ($P<0.001$, <0.001). The mean immobilization time in each group was not significantly different (31.4 ± 4.4 vs. 32.8 ± 5.9 d; $P=0.227$).

Conclusions: Although the postreduction quality was a little better and radiation exposure was less in the CRPP group, there was no difference between the 2 groups in angulation, total immobilization time, or complication rates after 6 months. The cost and time absent from school of patients in the nonoperative group was significantly lower than in the operative group. There is no clear advantage to CRPP treatment on outcomes. Therefore, closed reduction and casting is recommended in complete distal forearm fractures of children 8 to 14 years old.

Level of Evidence: Level III—therapeutic study.

Key Words: complete distal forearm fractures, children, treatment

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Pediatric forearm fractures are very common in the emergency department, and management of these injuries is challenging. Treatment of complete fractures of the distal third of the forearm are controversial. Pediatric forearm fractures may heal with an angular deformity although the deformity may decrease over time because of angular correction caused by remodeling associated with growth.[1] Distal forearm fractures involve fractures of the radial epiphysis and metaphysis. These locations have exceptional remodeling potential. Although proper traditional manipulative reduction treatment may lead to effective results, it has been challenged in favor of surgical intervention as technology has improved. However, it is uncertain if surgical intervention leads to superior outcomes. Operative treatment generally has been at the discretion of the attending surgeon and tends to be dictated by skeletal maturity in addition to patient age and stability of the fracture. Surgeons are often hesitant to treat patients 8 to 14 years old surgically. Children younger than this have a strong skeletal remodeling capability and surgical treatment is rarely needed. If the patient is older than 14, they may not have two years of growth remaining. The purpose of this study was to retrospectively compare outcomes between nonoperative and operative treatment of complete distal forearm fractures in patients who have at least 2 years of remaining skeletal growth.

METHODS

After approval from the Institutional Review Board, a retrospective chart review was carried out of all patients treated for complete distal third forearm fractures (including both radius and ulna, isolated radial fractures, and injuries to the epiphysis) between 2010 and 2017 at Children's Hospital of Soochow University, a large children's medical center in Jiangsu Province. Patients were identified by IDC-10 codes for forearm fractures (code no. S52). Exclusion criteria included open fractures, mid-diaphyseal and proximal fractures, intra-articular fractures (ie, Salter-Harris type-III or IV fractures), buckle or greenstick fractures, fractures with neurovascular compromise or compartment syndrome, floating elbow, distal radioulnar joint or elbow dislocations, critically ill patients, patients requiring emergency computed tomography scanning, inadequate documentation, or follow-up less than 6 months.

The decision for patients to be treated operatively or nonoperatively was at the discretion of the pediatric orthopaedic surgeon, 9 of whom were involved in this study.

In the nonoperative group, the Emergency Department physician provided conscious sedation before fracture reduction and casting using standard C-arm fluoroscopic guidance. The reduction was managed by a senior or attending pediatric orthopaedic surgeon. After reduction, patients were immobilized by a fiberglass cast. A 3-point mold was used to minimize the chance of loss of reduction. Attention was paid to the thickness of the padding, molding of the distal and proximal parts of the cast as well as at the fracture site with each roll of the cast material. Postreduction radiographs were taken after all fracture reductions to evaluate the adequacy of reduction. Metaphyseal distal radial and ulnar fractures were allowed a wide range of acceptability, with 30 degrees of sagittal and 20 degrees of coronal plane angulation in patients 9 years of age or younger. In older children with at least 1 year of growth remaining, 20 degrees of sagittal and 15 degrees of coronal plane angulation were permitted.[2]

The patient was discharged with instructions for strict elevation of the arm to accelerate the subsidence of swelling and educated about the warning signs of compartment syndrome. In the nonoperative group, children returned for evaluation weekly until the cast was removed. Radiographic union was defined from 2 orthogonal films as the presence of bridging callus on 3 of 4 cortices.

For operative treatment, the patient was taken to the operating room for a closed reduction and percutaneous pinning (CRPP) under general anesthesia. The arm also was immobilized by a fiberglass cast. A window was sawed into the cast to facilitate changing the dressing (Supplemental picture, Supplemental Digital Content 1, http://links.lww.com/BPO/A385). Patients undergoing operative treatment were hospitalized for observation 1 to 2 days. Patients in each group were followed for at least 6 months after the initial treatment.

Patient demographics, diagnosis, fracture site and pattern, and the angulation in both the coronal and sagittal planes measured on the initial and subsequent radiographs were recorded.

Outcome measures included the angulation after reduction, residual angulation at final follow-up, radiation exposure, total immobilization time, days absent from school (counting from the day discharged from the hospital), cost and complications such as repeated reduction, cast abrasion, scald injury by the saw, and pin site infection.

Inclination angles were measured on radiographs from the institutional picture archiving and communication system. Fractures involving only the ulna were rare and often accompanied by insufficient documentation. As the radius is the main component of the wrist, the distal radius physeal inclination angle was measured as the angle of deformity. This angle was defined by the longitudinal central axis of the distal one-third of the proximal radius and a line drawn through the physis of the distal radius.[3–5]

Radiation exposure estimates for each radiograph and each fluoroscopic image with the C-arm were made by an institutional radiation physicist based on testing of the x-ray machine and C-arm. Mean radiation exposure of a traditional radiograph is 16.2 mrem and 4.1 mrem per fluoroscopic image.

Statistical Analysis

Operative and nonoperative groups were compared with use of the Student t tests for continuous variables and χ^2 tests for categorical variables. Mann-Whitney tests were used for data that were not normally distributed. IBM SPSS Version 25.0 (IBM Corp, Armonk, NY) was utilized for statistical analyses. A P-value ≤ 0.05 was considered significant.

RESULTS

From 2010 to 2017, 290 complete distal forearm fractures in children aged 8 to 14 years old were treated at our institution. On the basis of the criteria previously described, 175 patients were included in the final study. Of the 175 fractures, 114 were managed operatively, and the remaining 61 were treated with closed reduction and casting. There were 69 girls and 106 boys, and the mean age was 10.59 years (Table 1). Twenty-three patients fractured both radius and ulna, 65 had isolated radius fractures, and 87 had injuries involving the epiphysis (Salter-Harris type-I or II fractures; Fig. 1). Age, sex, and fracture location distributions were similar between groups.

Prereduction and postreduction radiographs, along with 6-month follow-up radiographs, were recorded for all patients. The prereduction angulation of both anteriorposterior and lateral radiographs were similar in each group ($P=0.229$, 0.738). Although the postreduction

TABLE 1. Demographic Data on Patients in Each Group

	Operative Group	Nonoperative Group	P
Number of patients	61	114	
Age (y)	10.8 ± 1.6	10.5 ± 1.7	0.17*
Sex			
Male	37	69	0.98†
Female	24	45	

*The values are given as the Mann-Whitney U test.
†The values are given as the χ^2 test.

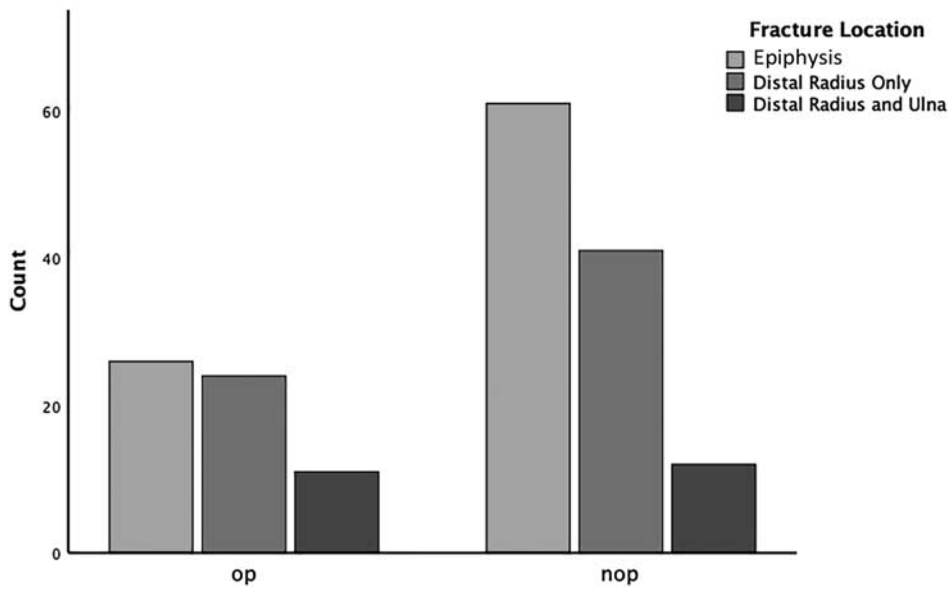

FIGURE 1. Fracture location distributions in each group. The distributions were similar ($P=0.256$).

coronal plane angulation was not significantly different between groups, the residual angulation in the sagittal plane was significantly lower in the CRPP group ($P=0.037$). The residual deformity after 6 months was not significantly different between groups in either the sagittal or coronal planes ($P=0.486$, 0.726).

Complete documentation for the total number of images acquired for evaluation of a reduction was available for 175 patients. Total radiation dose was calculated as the number of radiographs in each group and the average radiation exposure from each image. On the basis of this calculation, patients in the nonoperative group received significantly more radiation than those in the operative group ($P<0.001$).

The mean immobilization time in each group was not significantly different (31.4 ± 4.4 d vs. 32.8 ± 5.9; $P=0.227$). In the nonoperative group, absence from school averaged 4.3 ± 2.3 days compared with 5.4 ± 1.5 days in the operative group ($P<0.001$).

The hospital accounting system was used to collect data for the total cost of each individual patient. There was a significant difference in the cost of treatment by group with an average cost of $2136 per CRPP patient, and $635 per patient in the nonoperative group ($P<0.001$).

Treatment complications are shown in Table 2. Most complications were minor. Four patients required an unplanned additional reduction and 1 patient required oral antibiotics for pin site infection. The complication rate was 3.3% (2 patients) for CRPP and 5.2% (6 patients) in the nonoperative group ($P=0.827$).

DISCUSSION

Currently, there is a lack of consensus about the treatment of distal forearm fractures in the pediatric patient population. Nonoperative treatment is usually recommended for distal forearm fractures because of the elevated remodeling potential after fracture.[6,7] However, recent articles have suggested a trend toward more surgical intervention for pediatric and adolescent forearm fractures.[8,9] This trend may be the result of advanced technology, family and surgeon dissatisfaction with residual deformity, and challenges to historic standards of care.

It has been reported that surgeons who had hand fellowship training may recommend surgical treatment 2.9 times more often than surgeons with pediatric orthopaedic fellowship training.[7] Helenius and colleagues published a review of all pediatric and adolescent fractures treated in Finland between 1997 and 2006. The number of forearm fractures

TABLE 2. Comprehensive Follow-up and Cost Data on Patients in Each Group

Outcomes	Operative Group	Nonoperative Group	*P*
Reduction quality (average degrees)*			
Prereduction, CP	13.7	12.7	0.229
Prereduction, SP	24.4	23.9	0.738
Postreduction, CP	2.1	1.6	0.208
Postreduction, SP	2.9	4.5	0.037
Final follow-up, CP	0.3	0.2	0.726
Final follow-up, SP	0.6	0.5	0.486
Radiation exposure (mrem)*	81.0 ± 9.7	106.9 ± 16.0	< 0.001
Total immobilization time (d)*	31.4 ± 4.4	32.8 ± 5.9	0.227
Absence from school (d)*	5.4 ± 1.5	4.3 ± 2.3	< 0.001
Cost (dollar)*	2136 ± 310	635 ± 294	< 0.001
Complications			
Cast abrasion	0	1	
Scald injury by the saw	0	2	
Pin site infection	1	0	
Repeat reduction	1	3	
Complication rate, (%)†	3.3	5.2	0.827

*The data are not normally distributed so comparisons are from the Mann-Whitney *U* test.

†The values are given as χ^2 tests by continuity correction ($n>40, 1<T<5$).

CP indicates coronal plane; SP, sagittal plane.

treated by surgical procedures increased 32% during this period. This increase in surgical treatment of forearm fractures was seen most dramatically in the 8-year to 14-year age group (78%) and the 15-year to 17-year age group (90%).[10] Although the periosteum of children at this age is relatively thin, the bone still has a robust capability for remodeling.

CRPP improves the quality of the initial fracture reduction, but there was no significant difference radiographically between the 2 groups in angulation after 6 months. This suggests that patients managed nonoperatively will have acceptable reductions regardless of whether CRPP or closed reduction and casting is used.

The Friberg equation ($V_t = V_0\ e^{-\beta t}$) has been recommended for patients who have fractures of the distal forearm and at least 2 years of remaining skeletal growth.[3–5] The residual angulation (V_t) is predicted by the time after the fracture (t), the initial physeal inclination angle (V_0) and the empirically determined correction factor (β). Although Friberg believes "one cannot assume that complete normalization will take place after a distal forearm fracture healing with a primary angulation of > 20 degrees," patients in other studies with angulations as great as 39 degrees had remodeling consistent with the equation's exponential prediction.[11]

In our institution, accepted parameters include < 30 degrees in the distal forearm in the sagittal plane and < 20 degrees in the coronal plane in boys younger than 10 years of age and girls younger than 8 years of age. In boys and girls older than this, < 20 degrees of angulation is acceptable in the sagittal plane, and < 15 degrees in the coronal plane. In children older than 14 years, the accepted parameters are < 10 degrees of angulation in both planes. Greater amounts of fracture angulation may be acceptable in younger children who have sufficient time available for remodeling. A more tolerable standard of angulation may help avoid unnecessary fracture reduction procedures that may contribute to premature physeal closure or bar formation.

Our study demonstrated a meaningful difference in radiation exposure between the 2 groups. In the opinion of most surgeons, nonoperative treatment requires multiple visits to ensure ongoing maintenance of fracture alignment. More frequent radiographic review in the nonoperative group can expose the patient to more radiation. Garrison compared 141 patients with or without malunion and reported that the likelihood of malunion was not significantly associated with the number of clinic visits or number of radiographs.[12] On the basis of 279 displaced forearm fractures treated with closed reduction and casting, Lee et al[13] concluded that use of the mini C-arm to assist in the closed reduction of pediatric forearm fractures can decrease radiation exposure dramatically. In our opinion, the radiation dose is quite low and controllable, and should not be the crucial determinant for the choice of treatment.

Total immobilization time in each group was similar but patients in the operative group missed more classes. Communication with the families of CRPP patients suggested that parents tend to believe their children have sustained a much more serious fracture if treated surgically and needed additional rest and nursing. Not only is extra nursing unnecessary but as most households in China are dual-earner families this increases the burden on the family.

The cost of CRPP is more than 3 times greater than the cost of closed reduction and casting. Patients whose reductions were not satisfactory or who had marked angulation but delayed initial treatment may undergo repeated reduction, closed pinning or internal fixation. When a surgical procedure was performed, the patient was hospitalized and received a series of examinations, which increased costs significantly. Pearce and colleagues recommend using the Friberg equation to predict remodeling that may help avoid unnecessary fracture reduction procedures. In our population, avoiding an unnecessary surgical procedure could save an average of $1500 per patient.

Complications in the nonoperative group such as cast abrasion or scald injury by the saw can be avoided by increasing the thickness of the cotton pad and sawing the cast carefully. One patient required oral antibiotics for pin site infection from *Pseudomonas aeruginosa*. Four patients required repeated fracture reductions. In the CRPP group, one fracture required a second closed reduction and casting after taking out the Kirschner wire <3 weeks after surgery. We believe this was because of early removal of the pin. Three of the nonoperative patients with angulation of 20 to 30 degrees in the sagittal plane proceeded to re-reduction and casting in the outpatient department. None needed to convert to CRPP.

There are several limitations to our study. First, patients were not randomly assigned to each treatment exposing them to probable selection bias based on the choices their surgeons made. A follow-up minimum of 6 months has the potential to underestimate complications such as premature physeal closure or bar formation, which may lead to additional treatment. Further research investigating factors like motion, cosmetic appearance, function, pain, and return to activities are needed. Finally, only angular deformity was evaluated but malrotation, which can affect outcomes, was not addressed in this study.

Although this study demonstrates the significant difference in postreduction quality and radiation exposure between CRPP and closed reduction and casting in the treatment of complete distal forearm fractures in 8-year to 14-year old children, it is still unclear if CRPP treatment improves outcomes. There was no difference in angulation, total immobilization time, or complication rates between the 2 groups after 6 months. Moreover, the cost and time absent from school of children in the nonoperative group was significantly lower than in the operative group. Therefore, noninvasive treatment is recommended for complete distal forearm fractures if 2 years of growth potential remain for the patient.

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