

Original Research

Variations in the Preferred Treatment of Pediatric Forearm Fractures Among Practicing Orthopaedic Surgeons

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Abstract:

Background: Forearm fractures are common childhood injuries. Controversy remains on the optimal treatment for certain fractures. The goal of this study was to determine variation in the treatment of pediatric forearm fractures based on fracture patterns, patient demographics, and surgeon characteristics.

Methods: A survey was distributed to orthopaedic surgeons consisting of 48 different cases of pediatric forearm fractures with possible treatment options. Each case included patient age and radiographs at three different time intervals: initial injury, post reduction, and first office follow-up. Respondents were asked if they would recommend non-surgical management, surgery with intramedullary nailing, or surgery with plate/screw fixation. Surgeon demographic data was also collected. The primary model investigated the effect of the attributes on the surgeon's decision to operate.

Results: 48 of 55 surgeons responded. Surgery was chosen as preferred treatment in 43% of the presented scenarios. Coronal plane angulation at first follow-up was associated with the greatest increase in marginal probability of operative treatment. For each degree increase in angulation, respondents were 5.2% more likely to operate on a patient. For each additional year of patient age, operative treatment probability increased by 3.9%. Surgeons' sex, age, years in practice, and fellowship type were not associated with variations in treatment preferences.

Conclusions: Our study demonstrates significant variability in treatment recommendations among orthopaedic surgeons with regard to pediatric forearm fractures. Patient age and coronal plane angulation at first follow-up increased the probability of choosing operative treatment among respondents. Surgeon characteristics did not predict treatment recommendations.

Level of Evidence: III

Key Concepts:

- Age and coronal plane angulation increased the probability of orthopaedic surgeons choosing operative treatment of pediatric forearm fractures.
- A plate and screw construct was more likely to be the preferred treatment option in older patients with forearm fractures.
- Surgeon characteristics such as age, years in practice, and training did not predict treatment recommendations.

Introduction

Pediatric forearm fractures remain one of the most common childhood traumatic injuries.¹⁻⁴ Despite their prevalence, variation remains among orthopaedic surgeons regarding the preferred treatment of pediatric forearm fractures and there is limited evidenced-based criteria on how certain fractures should be optimally managed.⁵ In general, orthopaedic surgeons base treatment decisions on fracture pattern, patient age, and amount of growth remaining. Variation can be seen in a number of areas regarding the management of these injuries. For example, in a study examining distal radius fractures, treatment variation was found surrounding the type of immobilization, duration of immobilization, the interval between follow-up appointments, and the necessity of follow-up radiographs.⁶

Several forearm fracture treatment options exist for children and adolescents, ranging from closed reduction and casting to several variations of operative management. Although the traditional way to treat pediatric forearm fractures remains closed reduction and casting, there has been an increasing shift from non-operative management to operative intervention.⁷⁻¹⁰ The two primary surgical treatment options include closed or open reduction with intramedullary fixation and open reduction with plate and screw fixation. Intramedullary fixation with flexible intramedullary implants has increased in popularity as a minimally invasive approach to forearm fracture fixation. The introduction of

intramedullary nailing techniques has been a notable contributor to the recent increase in the surgical treatment of pediatric forearm fractures.⁵ Despite the increased use of these methods, consideration of the cost and potential complication rates associated with these methods should be taken into account, and surgery should be reserved for patients who will not achieve suitable results after closed treatment.

Surgeons may choose specific treatment methods for a number of reasons. The primary purpose of this study was to identify the variation of treatment recommendations based on patient and injury attributes among orthopaedic surgeons treating pediatric forearm fractures. The secondary aim was to assess the sources of this treatment variation if present.

Materials and Methods

Study Design

The study used a discrete choice experiment (DCE) design to determine the patient attributes that influence a surgeon's treatment decision. DCEs are a quantitative technique for eliciting preferences by asking individuals to state a preferred option in hypothetical scenarios described by a set of decisional attributes.

Development of DCE Survey

It was hypothesized that a surgeons' pediatric forearm fracture treatment preference would be influenced by the

radiographs and three patient factors including patient age, gender, and primary sport or activity. A series of 100 consecutive pediatric forearm fracture patients treated over a 2-year time frame at a single institution were reviewed. Of the 100 cases, 12 cases were selected by the senior author, which represented a spectrum of injury severity.

From each of the selected cases, a set of radiographs were taken at three different time points after the injury: initial injury radiographs, post reduction radiographs, and radiographs taken at the initial outpatient visit. The physes of each patient were censored to avoid influencing decision-making based on the appearance of the physes. The radiograph sets were then labeled with three patient factors: age, gender, and sport played. For the survey, the patients' age was varied from 8 to 14 years and the primary sports included tennis, gymnastics, soccer, and track and field.

Each set of radiographs was in the slide deck four different times with varied patient factors, giving us a total of 48 unique cases. The Choice Design package in JMP Pro Version 14 (Cary, NC) was used to create 48 cases from the 12 radiograph sets and 3 patient factors using an orthogonal, fractional factorial design.

PowerPoint (Microsoft Corp., Redmond, WA) slide decks of individual cases were assembled for each of the 48 cases (Figure 1). The slide decks were then integrated into a survey using Qualtrics software (Qualtrics, Provo, UT). The online survey was distributed to a convenience sample of 55 orthopaedic surgeons who treat pediatric forearm fractures. For each case, survey respondents were asked if they would recommend non-surgical management, surgery with intramedullary nailing, or surgery with plate/screw fixation based on the information provided. Surgeon demographic data were collected, including age, sex, fellowship type, and years' experience.

The angulation of the fracture was measured on the original anterior-posterior (AP) and lateral radiograph in EPIC (Verona, WI) at two different time points: initial injury and first follow-up. In addition, the difference of the measurements at these two time points were measured. The angulation values were not available to respondents during the survey.

Statistical Analysis

The demographic characteristics of the respondents were described using counts with proportions for nominal data and means with standard deviations or

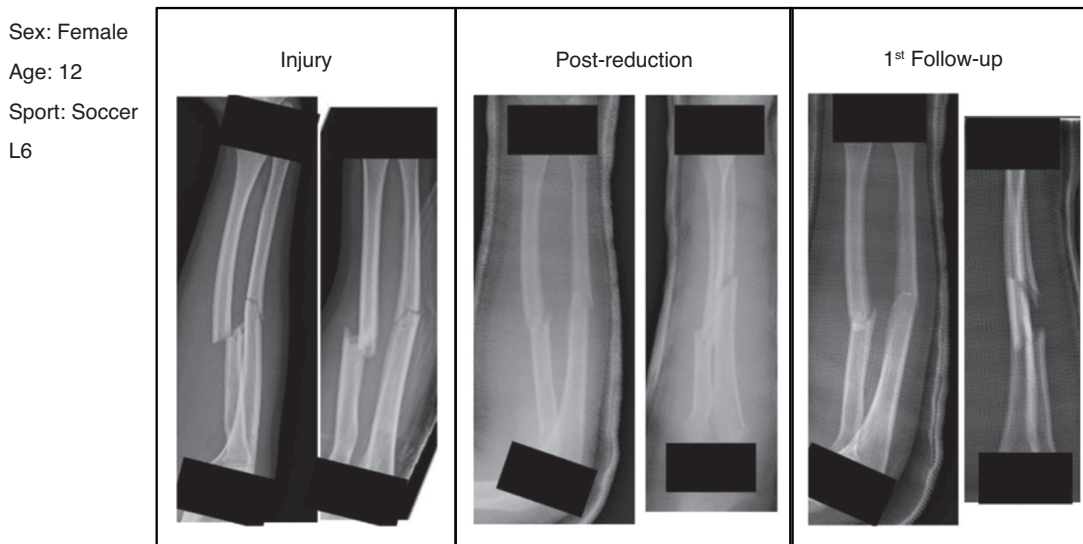


Figure 1. Example slide showing patient specific characteristics in top left with three sets of radiographs obtained at different time points.

medians with interquartile ranges for continuous data. The effect of patient attributes on the treatment decision was estimated using mixed effects logistic regression models. The primary model investigated the effect of the patient attributes on each surgeon's decision to operate. The secondary model investigated the effect of patient attributes on the surgeon's decision to use plates and screws as opposed to an intramedullary nail in the subset of patients that they opted to treat operatively. Six primary and six secondary models were investigated with varying definitions of angulation, including angulation measured at injury in the coronal plane, angulation measured at injury in the sagittal plane, angulation measured at follow-up in the coronal plane, angulation measured at follow-up in the sagittal plane, and the difference between the angulation at injury and follow-up in both planes. The optimal primary and secondary models were selected based on a minimal Bayesian Information Criterion (BIC). The marginal probability of operative treatment for each included attribute in the primary model was reported. In the secondary model, the marginal probability of treatment with plates and screws over an intramedullary nail was reported. The marginal probability for angulation can be interpreted as the increase in the probability of a given treatment for each degree increase in angulation within the included range for the model. Similarly, the marginal probability for age can be interpreted as the increase in the probability of a given treatment for each additional year of age within the age range included in the model. The model variance associated with individual surgeon preference was assessed using interclass correlation coefficients (ICC). Heterogeneity in preferences was assessed by adding the respondent characteristics as a random slope into the primary model. The predictive value of angulation measure for the decision to surgically treat the injury was assessed using c-statistics. In this study, the c-statistic can be interpreted as the probability of correctly identifying the treatment decision given the degree of angulation. The analyses were performed using R Version 3.6.0 (Vienna, Austria) with the packages *skimr*, *lme4*, *pROC*, and *margins*, and JMP Pro Version 14 (Cary, NC).

Results

The survey was distributed to 55 surgeons across the United States, of which, 48 completed the survey. The mean age of the respondents was 47.0 years (SD: 8.5, Range: 35-65) and 73% were male (Table 1). Half of the respondents had more than 12 years of practice experience. Seventy percent of respondents had completed pediatric orthopaedic fellowships, 39% had completed a hand fellowship, and 10% completed both hand and pediatric fellowships.

Respondents opted for surgical treatment in 43% of the presented hypothetical scenarios. Baseline preferences towards surgical treatment among individual respondents accounted for 18% of the overall variation observed in the analysis and varied significantly among the respondents (Figure 2).

Among the six primary models, the inclusion of the angulation measured at follow-up in the coronal plane provided the optimal model fit (Table 2). Angulation was also associated with the greatest increase in the marginal probability of operative treatment. For each degree increase in angulation in the coronal plane at the outpatient visit, the respondents were 5.2% (95% CI: 4.9–5.6) more likely to operate on a patient. For each additional year of age of the patient, the probability of operative treatment increased by 3.9% (95% CI: 3.2–4.5). A patient of female sex was 4.8% (95% CI: 1.9–7.6) more likely to be treated operatively compared to male patients. Respondents were indifferent to treatment

Table 1. Characteristics of Respondents (n=48)

Characteristic	
Age, years, mean (SD)	47.0 (8.5, 35-65)
Sex, male, n (%)	35 (72.9)
Years in Practice, median (IQR)	12 (7.8–21.3)
Pediatric Orthopaedic Fellowship, n (%)	34 (70.8)
Hand Fellowship, n (%)	19 (39.6)

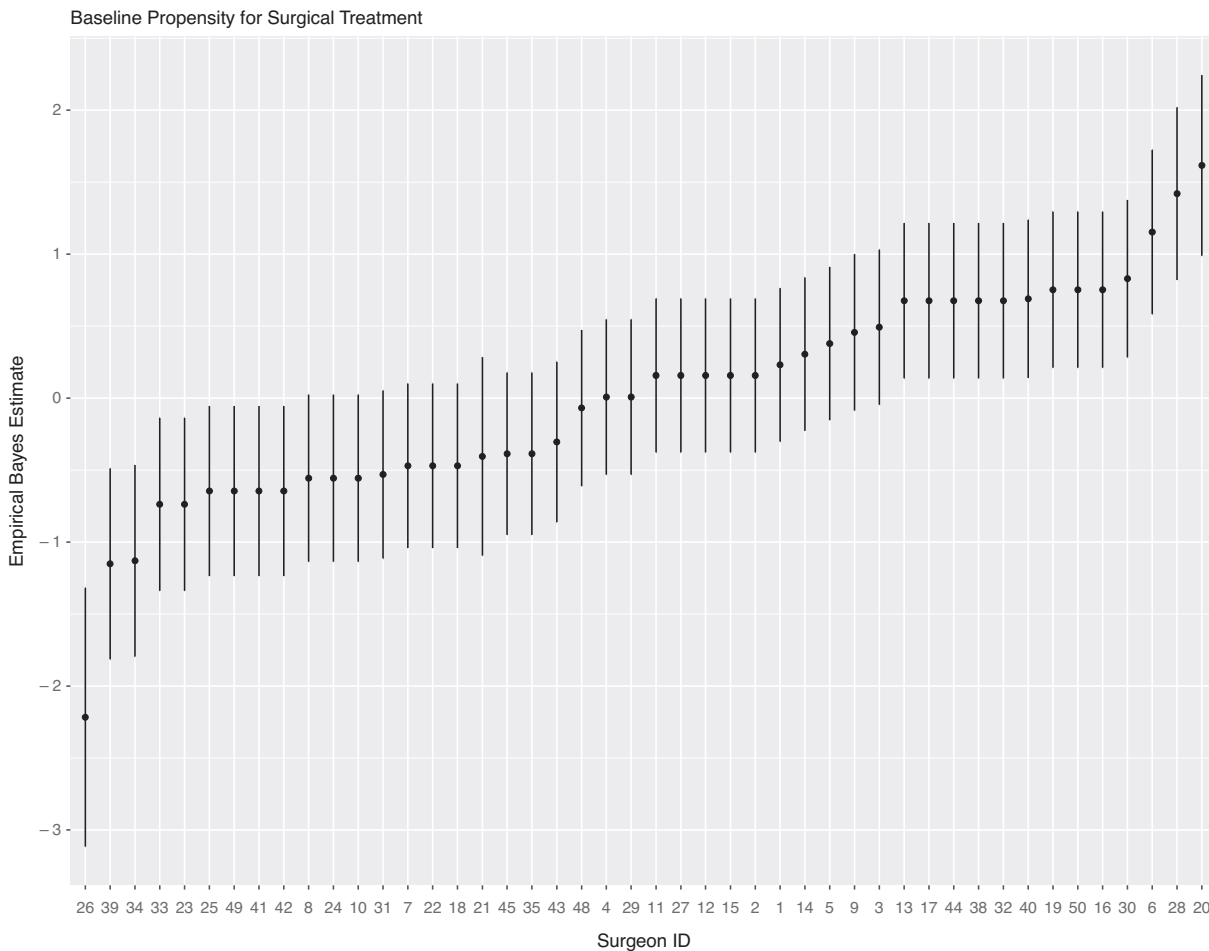


Figure 2. Baseline propensity for surgical treatment among individual respondents. Positive values on the Y-axis represent increased baseline likelihood the surgeon would choose operative intervention.

options based on the primary sport of the patient, with the exception of gymnasts who were 5.1% (95% CI: 1.0–9.1%) more likely to have surgical treatment than soccer players.

Heterogeneity in the treatment decision was tested based on the surgeons’ sex, age, years in practice, and type of fellowship. No evidence was found that these respondent characteristics were significantly associated with variations in their treatment decisions.

The secondary model evaluated the effect of patient attributes on the decision to use plates and screws versus an intramedullary nail to treat the fracture in the subset of patients in which the respondent selected operative treatment. In this model, patient age was the only attribute that significantly affected the type of surgical

treatment. Specifically, each year of age increased the probability of treatment with plates and screws by 9.0% (95% CI: 7.2–10.8). Similar to the primary model, there was no evidence of heterogeneity in treatment preferences based on the respondent’s characteristics.

A tremendous variability in the angulation measure’s ability to correctly predict the treatment decision was observed (Table 3). Of the tested measures, the angulation measure at follow-up in the coronal plane had the largest c-statistic (0.85, 95% CI: 0.83–0.86). This means that if a patient that was treated operatively and a patient that was treated non-operatively were selected at random from the sample, the probability that the patient with a greater degree of angulation at follow-up on the coronal plane would be treated operatively was 85%. The

Table 2. Marginal Effect of Patient-Level Attributes on the Treatment Decision

Patient Characteristics		Primary Model – Operative vs. Non-operative Treatment			Secondary Model – Plates & Screws vs. IM Nail		
Attribute	Level	Marginal Probability of Surgical Treatment	95% CI	P-Value	Marginal Probability of Treatment with Plates & Screws	95% CI	P-Value
Angulation on Coronal Plane at Follow-Up	Per Degree	5.2	4.9 -5.6	<0.01	0.2	-0.2-0.5	0.36
Age	Per Year	3.9	3.2-4.5	<0.01	9.0	7.2-10.8	<0.01
Sex	Female	4.8	1.9-7.6	<0.01	3.1	-0.1-6.3	0.06
Sex	Male	Reference (0.0)			Reference (0.0)		
Sport	Gymnastics	5.1	1.0-9.2	0.02	3.4	-1.0-7.9	0.13
Sport	Tennis	2.3	-1.7-6.3	0.26	0.7	-3.7-5.1	0.75
Sport	Track & Field	0.5	-3.5-4.6	0.80	-2.3	-6.7-2.1	0.31
Sport	Soccer	Reference (0.0)			Reference (0.0)		
No. of Observations		2183			956		
Model Fit (BIC)		1765			636		

Table 3. C-statistic of Angulation Measures for Primary and Secondary Comparison

Angulation Measure	Operative vs. Non-Operative Treatment		Plates & Screws vs. IM Nail	
	C-statistic	95% CI	C-statistic	95% CI
Sagittal at Injury	0.58	0.56-0.61	0.48	0.44-0.52
Coronal at Injury	0.58	0.56-0.61	0.47	0.42-0.50
Sagittal at Follow-up	0.64	0.62-0.66	0.47	0.43-0.51
Coronal at Follow-up	0.85	0.83-0.86	0.42	0.39-0.46
Difference from Injury to Follow-up, Sagittal	0.69	0.67-0.71	0.47	0.43-0.51
Difference from Injury to Follow-up, Coronal	0.43	0.40-0.45	0.49	0.46-0.53

difference in angulation from injury to follow-up on the sagittal plane had the next strongest predictive ability (c-statistic: 0.69, 95% CI: 0.67-0.71). When attempting to predict which operatively treated patients would be treated with plates and screws compared to those treated with an intramedullary nail, none of the included angulation measures performed better than random chance.

Discussion

Pediatric forearm fractures are common, and most fractures can be treated with traditional non-operative management.^{2,5,11} Closed reduction and casting is often a successful method with minimal complications while maintaining functional forearm rotation and range of motion. Eismann et al. noted that the majority

of studies examining pediatric upper extremity fractures recommended less aggressive or conservative treatment.¹¹ Flynn et al. noted that satisfactory results were found in 85% of patients who had displaced forearm fractures who underwent closed reduction.¹⁰ Tarmuzi et al. observed that among 48 forearm fractures of children aged 4-12 that utilized closed reduction and casting, 47 reported good outcomes.¹²

With regard to surgical management, Flynn et al. observed that most patients undergo surgery because closed reduction alone may not achieve satisfactory alignment.¹⁰ Surgery also tends to occur in older adolescent patients because of the decreased amount of years of remaining growth and remodeling potential.^{5,13} Most surgical treatment options result in successful outcomes; however, these patients are exposed to the increased risk of surgical complications.² Kang et al. showed the large majority of patients who underwent intramedullary fixation for forearm fractures were pain free at the latest follow-up and had achieved full activity level, however, were exposed to complication risks.¹⁴ Smith et al. reported a 33% complication rate among those who underwent open reduction and internal fixation compared to 42% for those who underwent intramedullary nailing.¹⁵ Overall complication rates of intramedullary nail procedures are reported to range between 17% and 42%.⁵ In addition to complication rates, the cost to the patient and healthcare system as a whole must be considered when deciding on the optimal treatment of pediatric forearm fractures.^{13,16,17}

The current study demonstrated a significant amount of baseline variation among orthopaedic surgeons who treat pediatric forearm fractures. With regards to surgeon demographics, there was no statistically significant difference in treatment preferences associated with age, years in practice, and fellowship training among the surgeons that responded to the survey. The hypothesis that younger surgeons with fewer years in practice may favor surgical treatment of these injuries compared to senior surgeons was not confirmed.

With respect to patient factors, older age and female sex were found to have higher rates of preferred surgical management. Surgeons also preferred surgical treatment with plates and screws as opposed to intramedullary fixation in older patients. This finding is consistent with the idea that older patients have lower remodeling potential and thus need a more anatomic reduction for an optimal outcome.¹⁸ In addition, female skeletal maturity occurs at an earlier age, which may favor more operative management compared to males of the same age. Gymnasts had higher rates of preferred surgical management compared to soccer players. This may be due to anecdotal evidence that gymnasts place more stress on their upper extremities and require a more anatomic reduction compared to soccer players.

The most influential factor for the decision to recommend surgery was based on fracture angulation. Coronal and sagittal plane angulation at the time of the first outpatient follow-up visit had the highest predictive probability of operative treatment. The decision for operative intervention at this point was likely put in the context of the previous radiographs. Those with an increased angulation may have indicated to the surveyed surgeons that the fracture would continue to displace and lead to an unacceptable reduction. Fracture angulation had no influence on whether intramedullary fixation or plate and screw fixation was preferred, and patient age was the only factor that correlated with the specific type of surgical management.

There are several limitations to this study. First, this was a survey study distributed to pediatric orthopaedic surgeons and hand surgeons known by the two senior authors. In addition, there was a relatively small sample size of surgeons included in this study, and thus the respondent population may not be representative of the general orthopaedic surgeon population. Perhaps larger numbers in the subsets of orthopaedic specialties may have delineated a difference in these decisions. Another limitation is that surgeons were asked to make decisions based on radiographic images and were unable to measure

the angulation directly. Borderline cases may have been affected by the inability to directly measure these radiographs. Management decisions were based on the radiographs rather than talking to patients. In the office, surgical decision-making is highly influenced by patient and parent preferences in conjunction with surgeon recommendations. Additionally, by obscuring the physes to control for bias due to perceived age, we may have prevented surgeons from being able to assess malrotation on radiographs which may have influenced the treatment option chosen. Finally, results may have been influenced by the Hawthorne effect in which respondents make decisions with the knowledge they are being evaluated and compared to other respondents.¹⁹ The simple fact of knowing that one is being measured or tested, may affect how one responds to questions or surveys.

Conclusion

There is substantial variation in the baseline preferences for treatment of pediatric forearm fractures among the sampled group of orthopaedic surgeons in the current study. Surgeons' decision for surgical management is heavily influenced by the angulation seen at the first outpatient visit. Patient age and sex also influence the decision for operative management in pediatric forearm fractures. Although fracture angulation, patient age, and sex influence the decision to recommend surgical treatment, variation remains surrounding preferred treatment for these injuries. Future studies should focus on refining surgical treatment indications for pediatric forearm fractures.

Disclaimer

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