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Original Research

Hold that K Wire! Fixing Nondisplaced Distal Forearm Fractures in Pediatric Floating Elbow Injuries is Unnecessary

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ABSTRACT

Introduction: Floating elbow injuries are uncommon, combined injuries in children involving a supracondylar humerus fracture and a distal fracture of the forearm. Orthopaedic dogma has suggested that a more aggressive approach to the distal fracture is necessary due to the potential risk of acute compartment syndrome. Our group recently showed that the rate of compartment syndrome is less than one percent. As such, we hypothesized that concomitant nondisplaced distal forearm fractures managed with operative fixation would result in similar outcomes compared to nonsurgical treatment.

Methods: A multicenter retrospective database was queried for pediatric patients who presented with floating elbow injuries, defined as a supracondylar humerus fracture with a concomitant nondisplaced distal forearm fracture (AO OTA-23-M/2.1), between 2014 and 2019. Patient demographics, injury characteristics, treatment course, and outcomes were evaluated. Patients were compared based on the management strategy of the nondisplaced distal forearm fracture.

Results: A total of 102 patients (of the 454 patients in the database) met inclusion criteria, of which 26 (25.4%) underwent operative fixation, with an overall median follow-up of 2.2 months. With respect to distal fracture characteristics, there was no increased incidence of internal fixation of the forearm fracture in patients with a displaced supracondylar fracture (types 3 and 4) ($P = .563$). Total operative time was higher, but was statistically similar in the internal fixation (45.5 minutes) vs noninternal fixation (34 minutes) cohort ($P = .06$). A higher proportion of patients returned to early full activity in the nonfixation distal fracture cohort (80% vs 68%; $P = .04$). Other outcomes between fixation and nonfixation management were similar with respect to modified Flynn criteria, symptoms, persistent neurological deficits, and malunion. The overall rate of return to the operating room between cohorts was also similar (5% vs 3.8%; $P = 1.00$). No patient in either cohort was diagnosed with compartment syndrome or required fasciotomies.

Conclusion: While the rate of return to full activity at a median of 2.2 months was higher in the noninternal fixation group, other outcomes, including functional recovery, symptoms, complications, and reoperation rates, were similar between the two cohorts.

Key Concepts:

(1) Floating elbows are defined as a supracondylar humerus fracture paired with a distal both-bone or forearm fracture.
(2) In the past, this injury was thought to result in a high rate of compartment syndrome, though current studies refute that.
(3) An aggressive approach with the distal fracture may not be warranted in all cases, and closed treatment is acceptable in nondisplaced fractures.

Level of Evidence: III

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Introduction

Elbow injuries are among the most common musculoskeletal injuries in pediatric orthopaedics, accounting for nearly 10% of fractures sustained by children [1,2]. However, floating elbow injuries are rare and are defined by a concomitant ipsilateral fracture of the humerus along with a distal fracture of the forearm or wrist [3,4]. Historically, the literature has suggested a high risk of pediatric acute compartment syndrome and downstream poor outcomes, including devastating neurologic sequelae if not treated urgently [5–8]. However, our group recently established that this notion is attributable, at least in part, to the majority of literature examining greater morbidity in the adult population, cases with delayed treatment, or pediatric patients treated with circumferential casts [5,6,9–12]. We recently showed that the rate of compartment syndrome is less than one percent in pediatric floating elbow injuries [5].

Studies by Blakemore et al., Ring et al., and Templeton and Graham have shaped orthopaedic practice for decades, despite their studies being limited by small sample size [6,7,9]. These studies contained small series of displaced proximal and distal fractures and identified pinning both fractures as a strategy to provide stability in order to avoid circumferential casts. This more aggressive stance for the distal forearm fracture has largely been viewed as a take-home message for practitioners treating children with this injury, regardless of displacement. The findings of our previous study suggest that the natural incidence of compartment syndrome may be less than previously thought [5]. This may be partially explained by the current trend to avoid circumferential casting or bivalve casts in the setting of excessive swelling. Blumberg et al. demonstrated safe, nonoperative management of the ipsilateral forearm fracture in their institutional series of 47 patients [8]. Simultaneous closed reduction of a displaced forearm fracture with noncircumferential immobilization was not associated with an increased risk of morbidity [8]. Notably, this study included both torus and displaced distal fractures [8]. Similar studies have supported satisfactory clinical and radiographic outcomes with noninternal fixation management of the concomitant forearm fracture but have been limited to small, heterogenous case series [13,14].

Thus, the purpose of this study was to investigate the management and postoperative outcomes of nondisplaced distal forearm fractures in the setting of pediatric floating elbow injuries. This represents the largest pediatric floating elbow cohort to date, allowing us to isolate and characterize the treatment paradigms of the nondisplaced distal forearm fracture and evaluate clinical outcomes. We hypothesized that internal fixation of the concomitant nondisplaced distal forearm fracture would result in similar short-term outcomes compared to nonsurgical treatment.

Materials and methods

A retrospective database of pediatric floating elbow injuries was created across 15 institutions of the Children's Orthopaedic Trauma and Infection Consortium for Evidence-Based Studies (CORTICES, www.cortices.org), a nationwide collaboration of pediatric orthopaedic surgeons from level-I tertiary care pediatric trauma centers. Institutional Review Board approval and Data Use Agreements were obtained from each participating institution prior to data collection. The database consisted of patients from each institution under the age of 18 years who presented between May 1, 2014, and May 1, 2019, with floating elbow injuries, defined as a supracondylar humerus fracture and concomitant ipsilateral radius and/or ulna fracture [5]. The database was queried for patients whose floating elbow injury consisted of a supracondylar humerus fracture with a concomitant nondisplaced distal forearm fracture (AO Classification OTA-23-M/2.1). Elbow fractures other than the supracondylar humerus (i.e. humeral shaft, lateral condyle, or medial epicondyle) and displaced forearm fractures were excluded. Furthermore, patients with less than 6 weeks of clinical follow-up were excluded from this study.

Patient demographics, injury characteristics, treatment course, and clinical outcomes were evaluated. Patients were compared based on the management strategy of the nondisplaced distal forearm fracture. Early return to activity was defined as Modified Flynn outcomes criteria, which were used to assess outcomes at the final visit and were defined as "excellent" for 0- to 5-degree varus of Baumann angle and 0-degree range of motion (ROM) loss, "good" for >5- to 10-degree varus and <10-degree ROM loss, "fair" for >10- to 15-degree varus and 10- to 30-degree ROM loss, and "poor" for >15-degree Baumann angle and >30-degree ROM loss [5]. Full activity was defined as a returning to all baseline activity without restriction and full motion in accordance with their Modified Flynn criteria. "Limited" activity was defined as return to activity but less than previously (i.e. sport modification, different sport) while "very limited" was considered as a poor Modified Flynn score and unable to use the arm except as a helper hand.

Standard descriptive summary statistics were reported, including valid percentages for categorical variables and medians and interquartile ranges (IQR) for continuous variables. Univariate analyses were used to compare internal fixation and noninternal fixation treatment groups, including χ 2 tests, Fisher exact, or Mann–Whitney U tests as appropriate. All tests were two-tailed, and significance was set at $\alpha = 0.05$. All statistics were performed using SPSS Version 28 (SPSS Inc., Chicago, IL).

Results

A total of 102 patients with a nondisplaced distal forearm fracture, out of the 454 patients enrolled in the pediatric floating elbow database, were evaluated across the 15 institutions. The median age at the time of injury was 6.4 years (IQR: 5.2, 7.3 years). Overall, 40.2% of patients were male. The majority of patients sustained their injury after a high-energy fall (n = 78; 76.4%), defined as a fall from a height greater than the patient's own height. A total of 12.7% of patients presented with a neurovascular deficit, and 4 (3.9%) patients were pulseless at presentation.

Of the 102 patients with a nondisplaced distal forearm fracture (AO OTA-23-M/2.1), 26 (25.4%) underwent internal fixation of the forearm fracture, with an overall median follow-up of 2.2 months (IQR: 1.7, 4.7 months). Median age was similar in the internal fixation cohort vs noninternal fixation cohort ($P = .21$), while a higher distribution of females was noted in the fixation cohort ($P = .01$). Additional study demographics and injury characteristics are detailed in Table 1.

Treatment

The greatest percentage of supracondylar humerus fractures were Gartland type 3 (n = 47; 46.1%). With respect to distal fracture characteristics, internal fixation of the nondisplaced both-bone distal forearm fracture was not performed more often in patients with more displaced supracondylar fracture (types 3 and 4) ($P = .56$). Total operative time was also similar between the fixation and nonfixation distal fracture groups ($P = .06$) (Table 2).

Outcomes

A higher proportion of patients returned to full activity in the nonfixation nondisplaced distal forearm fracture cohort ($P = .04$) at the final follow-up. When this was adjusted for displacement of the supracondylar humerus fracture, patients with a displaced fracture showed no significant difference in return to activity when the distal forearm fracture was fixed vs when it was managed closed ($P = .75$). However, when patients with nondisplaced or minimally displaced supracondylar humerus fracture (types 1 or 2) who had their distal forearm fracture simultaneously instrumented trended toward being less likely to return to early full activity ($P = .06$) at a median of 2.2 months (Fig. 1). Other outcomes between fixation and nonfixation of the distal forearm fractures were similar with respect to modified Flynn criteria, symptoms,

Table 1.
Patient and injury demographics.

n = 102		Nondisplaced forearm fracture* Noninternal fixation n = 76	Internal fixation n = 26	*P*-value†
Age (years)		6.2 (5.0, 7.2)	6.4 (6.0, 7.4)	0.21
Sex	**Male**	36 47.4%	5 19.2%	0.01
	Female	40 52.6%	21 80.8%	
Height (cm)		116.0 (109.0, 123.8)	121.9 (116.6, 127.3)	0.06
Weight (kgs)		22.9 (18.0, 27.3)	24.0 (21.2, 28.6)	0.16
Race	**White**	52 68.4%	15 57.7%	0.10
	Hispanic or Latino	17 22.4%	5 19.2%	
	Black	6 7.9%	4 15.4%	
	Asian	1 1.3%	0 0.0%	
	Other	0 0.0%	2 7.7%	
Mechanism of injury	**High energy fall**	62 81.6%	16 61.5%	0.06
	Low energy fall	13 17.1%	7 26.9%	
	Sports	0 0.0%	1 3.8%	
	Motor vehicle accident	1 1.3%	2 7.7%	
Neurological deficit at presentation	**Yes**	9 11.8%	6 23.1%	0.16
	No	67 88.2%	20 76.9%	
Vascular at presentation	**Palp at wrist**	71 97.3%	22 88.0%	0.06
	Dopplerable at wrist	1 1.4%	0 0.0%	
	Pink and pulseless	1 1.4%	3 12.0%	
	Missing‡	3	1	
Follow-up (months)		2.2 (1.8, 2.9)	2.7 (1.7, 4.7)	0.60

* *Values represented as median (IQR: 25,75), n (%).*
† *Chi-square/Fisher's exact/Mann–Whitney U test.*
‡ *Missing values not incorporated.*

persistent neurological deficits, and malunion ($P > .05$) (Table 3). The overall rate of return to the operating room between the cohorts was also similar ($P = 1.00$), with no patients returning for management of their forearm fracture. Furthermore, no patient developed compartment syndrome or had fasciotomies.

Discussion

Optimal treatment of pediatric floating elbow injuries remains controversial. Generally, AO OTA-23-M/2.1 fractures are inherently stable and are both effectively and safely treated with brief periods of immobilization [15,16]. Moreover, pediatric forearm fractures in isolation have been shown to be successfully treated with closed reduction and immobilization alone in >90% of cases [17,18]. Although, surgical fixation also results in successful outcomes, it is associated with a significantly increased complication rate [17].

Floating elbow injuries, however, present a unique challenge in considering the cost-benefit ratio of treatment of the ipsilateral forearm fracture. Proposed benefits include stabilizing the distal fracture to mitigate the risk of compartment syndrome and reduce the risk of for return to the operating room for late displacement [8]. No patient in either group in this study was diagnosed with compartment syndrome, and our previous study showed an overall rate of compartment syndrome less than 1%, regardless of forearm fracture displacement. Earlier accepted practice was shaped by Ring and Templeton's suggestion that both the proximal and distal fracture should be treated with surgical fixation to mitigate compartment syndrome risk. Notably, however, these authors had a series of very displaced fractures and recommended fixing both the proximal and distal fractures to avoid a circumferential casting. Their work has been interpreted by many to suggest that both fractures should be fixed in all cases [6,7]. This strategy, however, is of unclear benefit, and circumferential casting was likely a larger

Table 2.
Fracture and treatment characteristics.

N = 102		Nondisplaced forearm fracture* Noninternal fixation n = 76	Internal fixation n = 26	*P*-value†
Humeral fracture type	**Gartland 1**	4 5.3%	2 7.7%	0.56‡
	Gartland 2a	18 23.7%	4 15.4%	
	Gartland 2b	20 26.3%	4 15.4%	
	Gartland 3	34 44.7%	13 50.0%	
	Gartland 4	0 0.0%	3 11.5%	
Forearm fracture type	**Isolated single bone (Radius/Ulna)**	44 57.9%	15 57.7%	0.99
	Both bone	32 42.1%	11 42.3%	
SCH fracture treatment	**Non-operative**	2 2.6%	0 0.0%	1.00
	Operative	74 97.4%	26 100.0%	
Post-operative immobilization	**Cast**	52 68.4%	20 76.9%	0.41
	Splint	24 31.6%	6 23.1%	
Operative time (mins)		34.0 (25.0, 55.5)	45.5 (30.7, 64.2)	0.06

* *Values represented as n (%).*
† *Chi-square/Fisher's exact test.*
‡ *P-value is based on comparison between Gartland 1-2 and Gartland 3-4.*

contributor to the historically elevated compartment syndrome risk of the past [7].

Prior studies have suggested that operative fixation of the supracondylar humerus fracture alone is sufficient but contained heterogenous samples [8,13,14]. Blumberg et al. demonstrated that forearm fixation was not necessary, and patients could be successfully treated with percutaneous fixation of the supracondylar fracture along with closed management of the forearm fracture and immobilization in a well-molded, valved cast [8]. Within their cohort, 26 patients had a torus fracture of the forearm, all of which were treated nonoperatively, who demonstrated favorable outcomes [8]. Ulus et al. showed similar results in their series of pediatric floating elbows, with no significant difference in clinical outcomes between operatively and nonoperatively treated forearm fractures in their 15-subject case series [14]. Karsli et al. demonstrated similar outcomes between nonoperative (n = 18) and operative (n = 42) treatment for forearm fractures in children with ipsilateral elbow fractures. Interestingly, fracture level was not the indicative factor for treatment; rather, stability following reduction

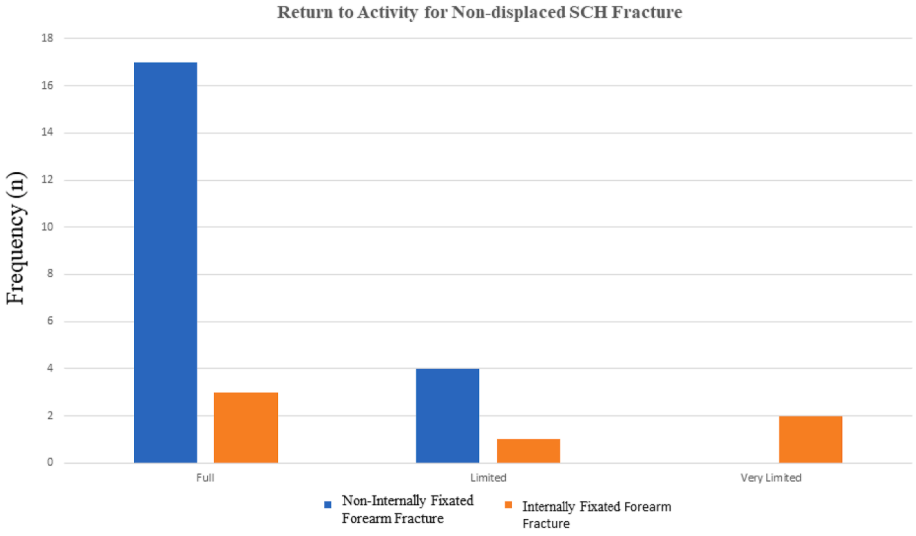

Figure 1. Level of return to activity at median follow-up of 2.2 months, based on management of the nondisplaced distal forearm fracture in cases with-nondisplaced supracondylar humerus fractures (Types 1 and 2).
***Full: Return to previous activity; Limited: Return to activity but less than previously (i.e. sport modification, different sport); Very Limited: Unable to use arm except as a helper hand.

Table 3.
Outcomes of internal fixation and nonfixation of the nondisplaced forearm fracture.

N = 102		Nondisplaced forearm fracture* Noninternal fixation n = 76	Internal fixation n = 26	*P*-value†
Modified Flynn criteria	**Excellent**	25 32.9%	11 42.3%	0.81
	Good	30 39.5%	9 34.6%	
	Fair	16 21.1%	4 15.4%	
	Poor	5 6.6%	2 7.7%	
Symptoms‡	**None**	61 80.3%	21 80.8%	0.20
	Mild	14 18.4%	3 11.5%	
	Moderate	1 1.3%	2 7.7%	
	Severe	0 0.0%	0 0.0%	
Return to activity	**Full**	60 80.0%	17 68.0%	0.04
	Limited	15 20.0%	6 24.0%	
	Very limited	0 0.0%	2 8.0%	
	Missing	n = 2		
Persistent neurological deficit (final visit)	**No**	74 97.4%	26 100.0%	0.40
	Yes	2 2.6%	0 0.0%	
Malunion	**Yes**	2 2.6%	0 0%	1.00
	No	74 97.4%	26 100.0%	

* *Values represented as n (%).*
† *Chi-square/Fisher's exact test.*
‡ *Activities of daily living and participation in sports.*

measured by angulation less than 15° in midshaft fractures, less than 10° in distal shaft fractures, and no angulation in proximal shaft fractures. With this criterion, there was no significant difference in radiographic or clinical outcomes, including range of motion, between the operative and nonoperative groups [13].

With our finding that floating elbow injuries are not commonly associated with pediatric acute compartment syndrome, consideration of the severity of the individual component injuries in surgical decision making is warranted, specifically in the setting of a concomitant nondisplaced distal forearm fracture [5]. While early return to full activity was higher in the nonfixation group, other outcomes, including functional recovery, symptoms, complications, and reoperation rates, were similar between the two cohorts. Our series showed that minimal risk for subsequent reoperation, and no patient returned to the operating room for issues related to the forearm fracture or for compartment syndrome. As AO OTA-23-M/2.1 fractures are inherently stable with little to no risk of becoming displaced, this data shows, unsurprisingly, that they can be effectively treated as they would be in isolated injuries [16].

Our study showed a decreased rate of early return to activity in internally fixated distal fractures compared to nonfixation distal fractures. These findings seem driven primarily by displacement of the proximal fracture. We found no difference in early outcomes between distal fracture treatment strategies in patients with significantly displaced proximal fractures (Gartland 3 or 4) or in minimally displaced proximal fractures (Gartland 1 or 2). In this latter group, fixated distal fractures had severe limitations in return to activity at a median of 2.2 months, occurring 33% of the time vs zero percent of the time in nonfixated distal fractures. This relationship is interesting but likely confounded by small sample size as this was a smaller subgroup of our entire sample. Additionally, it is possible this finding is premature; with longer follow-up, patients with more limited return might improve. Given that patients with nonfixated distal fractures appeared to fare at least similarly, consideration should be given to treating these injuries conservatively.

The results of this study should be considered in light of the following limitations. First, the retrospective study design of a multicenter database review is subject to inherent selection bias when identifying the cohort. In our original query, patients were identified through billing queries at each of the institutions in the consortium through Current Procedural Terminology codes for the treatment of humeral and radius/ulna fractures. Fractures were classified through using the AO/OTA classification and were reviewed by each site using a data dictionary provided to each site's PI. It is possible that floating elbow injuries were missed in these queries, specifically for nonfixated nondisplaced forearm fractures, biasing our selection toward those patients who underwent surgery and thereby affecting our conclusions. Although the chance of

misclassification exists, this is at least partially mitigated by pretesting of our data dictionary at pilot centers prior to its launch to all centers. Furthermore, there was not a standard method of postoperative immobilization for those treated nonoperatively. The postoperative immobilization method was subject to surgeon preference at each site. Short-term follow-up was perhaps the largest study limitation but is inherent to many trauma studies. Some of the patients classified as not having returned to full activity may have returned with longer follow-up, or by contrast, could have developed a late-presenting complication of surgery. We can at least state that during the first two months, during which time the nondisplaced distal forearm fracture would likely have healed, there appears to be no benefit of operative intervention in this setting.

Strengths of our study include the multicenter design, which allows our results to reflect the outcomes of a variety of surgeons' treatment plans across multiple high-volume, level-I tertiary care pediatric trauma centers, allowing for generalizability of our data. That said, our results may not be representative of outcomes of pediatric floating elbows seen at combined adult/pediatric centers or those with lower trauma capacity.

This multicenter study of the management and outcomes of nondisplaced distal forearm fractures in floating elbow injuries represents the largest, most homogenous cohort to our knowledge to date. Our data demonstrate that nonoperative treatment of the ipsilateral nondisplaced distal forearm fracture is safe and effective. While short-term return to full activity was higher in the noninternal fixation group, other outcomes, including functional recovery, symptoms, complications, and reoperation rates, were similar between the internal fixation and noninternal fixation cohorts. The incidence of compartment syndrome in this subgroup was zero, with or without fixation of the distal fracture. This information should help inform surgeons to reconsider surgical fixation of the distal nondisplaced forearm fracture in the setting of pediatric floating elbow injuries. Classic studies such as those by Ring, Blakemore, and Templeton encouraged fixation, but it is important to consider all other elements of the patient's treatment at the time. These studies encouraged fixation to limit circumferential immobilization; thus, if the fracture is inherently stable enough for a bivalved cast or splint, it can likely be treated without surgery.

Ethics approval and consent

The author(s) declare that no patient consent was necessary as no images or identifying information are included in the article.

Patient consent

This study was reviewed by each site's Institutional Review Board prior to data collection, and a waiver of consent was obtained.

Author contributions

Maia D. Regan: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Akbar Syed:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Keith D. Baldwin:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **CORTICES Study Group:** Conceptualization, Writing - review and editing, Methodology and data curation.

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Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

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