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Posterolaterally Displaced and Flexion Type Supracondylar Fractures are Associated with a Higher Risk of Open Reduction

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Abstract

Objective—To identify factors predictive of the risk of conversion from closed to open reduction.

Methods—ICD-9 codes were used to identify completely displaced pediatric supracondylar humerus fractures that underwent planned closed reduction and percutaneous pinning. Clinical and radiographic variables were retrospectively collected.

Results—Compared to posterior extension fractures, flexion [Risk Ratio (RR): 34.1, 95% CI: 8.1 to 143.6, $p < 0.0001$] and posterolateral extension [RR: 6.0, 95% CI: 1.3 to 27.5, $p = 0.0221$] fractures were significantly more likely to undergo conversion from closed to open reduction.

Conclusions—The direction of displacement should be considered during the pre-operative evaluation of supracondylar fractures.

Keywords

supracondylar humerus fractures; pediatric; open reduction

Introduction

Supracondylar humerus fractures (SCHF) are the most common type of elbow fracture in children [1]. These fractures are typically classified according to the position of the elbow at the time of the injury. Flexion type fractures represent a rare pattern, comprising only 1–10% of all supracondylar fractures [2–4]. Extension type fractures are further classified, based on Wilkin's modification of the Gartland classification system, according to the degree of displacement and continuity of the posterior humeral cortex [5, 6].

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The goal of surgical treatment is to achieve and maintain the anatomic alignment of the distal humerus and minimize the risk of neurovascular complications. The most accepted treatment method for completely displaced SCHF is closed reduction and percutaneous pin fixation [7, 8]. Immediate open treatment is recommended for fractures associated with compartment syndrome, an open injury and/or a compromised vascular status [9–11]. Conversion from closed reduction to open reduction is also required in cases where a stable reduction cannot be maintained and/or there are concerns regarding changes in the perfusion of the hand following the initial closed reduction. The rate of conversion from closed to open reduction due to an inability to maintain a stable, anatomical reduction has been reported to range from 2 to 46% [12–18].

Patient and fracture characteristics associated with the need for unplanned open reduction have not been well described in current literature. Therefore, the purpose of this study was to identify factors associated with the risk of open reduction among children undergoing planned closed reduction of completely displaced supracondylar humerus fractures.

Methods

Following Colorado Multi-Institutional Board (COMIRB) approval, ICD-9 codes were used to identify supracondylar fractures supracondylar humerus fractures that underwent planned closed reduction and percutaneous pinning between January 2004 and January 2012 (N=1,592). A chart review was used to identify completely displaced, type III or IV fractures with pre-operative radiographs (N=413). Fractures were then excluded for the following: undergoing planned open reduction due to vascular concerns or an open injury (N=14), missing clinic notes (N=11), underwent surgical management at an outside hospital (N=2), and/or underwent revision re-pinning (N=2, see Figure 1 for additional information). A total of 384 fractures were included in the analysis. A retrospective chart review was used to collect demographic and clinical characteristics. The occurrence of conversion from closed to open reduction was the primary outcome variable. The direction of fracture displacement, based on preoperative anteroposterior and lateral radiographs, was the primary explanatory variable. Fracture displacement was defined as the following: *Posterior Extension* - fracture segment is displaced posteriorly without coronal plane translation; *Posteromedial Extension* - fracture segment is displaced posteriorly and is translated medially; *Posterolateral Extension* - fracture segment is displaced posteriorly and is translated laterally, or *Flexion/Anterior* displacement.

Additional covariates evaluated in this study included age at surgery, attending surgeon, gender, year of surgery, presence of a concomitant fracture, time from diagnosis to surgery, body weight percentile, and location of initial referral. A total of 17 surgeons operatively managed the supracondylar fractures included in the study cohort. Surgeons that performed <25 fractures were collapsed into a single group. Surgeons that performed ≥ 25 surgeries were assigned to their own category within the surgeon group variable (See Table 1). The location of initial referral was defined as within network of care (surgical referral originated based on evaluation by provider affiliated with the institution) versus outside the network of care (surgical referral originated from provider who is not affiliated with the institution). Due to inconsistencies in the documentation of the time of initial injury (based on self-

report), time from diagnosis to surgery was based on difference in time of initial radiographic evaluation and surgery start time. This variable was categorized into the following levels: <12 hours, 12–24 hours, vs. >24 hours.

Statistical Methods

Descriptive statistics were used to characterize the demographics and clinical characteristics of subjects that underwent open reduction (open reduction group) versus those subjects that did not (closed reduction group). Weight percentiles, based on age and gender, were calculated using a publically available SAS (Statistical Analysis Software, Carey, North Carolina) macro that was downloaded from the Center for Disease Control and Prevention's website.[19]

The incidence of conversion from closed to open reduction and corresponding 95% CIs were calculated. Chi-square or Student's t-tests, when appropriate, were used to compare the distribution of demographics and clinical characteristics in the open reduction group versus the closed reduction group (Table 1). All factors that were significant, at the alpha level of 0.10 level, in the univariate analysis were tested in the multivariable model. A modified Poisson regression analysis was used to estimate risk ratios for all variables included in the final model multivariable. According to the methods described by Zhao G [20], the variance associated with the parameters was modeled using the robust or sandwich variance estimator. During the model building step of the analysis, interactions between variables included in the model were considered. Only interactions significant at the alpha level of 0.05 were included in the final model.

Due to the large number of subjects with missing pre-operative radiographs, a secondary analysis was undertaken to compare the distribution of demographics among with missing radiographs as compared to subjects with complete radiographic data. Chi-square or Student's t-tests, when appropriate, were used to compare the distribution of demographics across the two groups. The data analysis for this paper was generated using SAS software, Version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

The incidence of the need for conversion from closed to open reduction was 7.0% [95% CI: 4.7 to 10.1%]. The demographics and clinical characteristics of subjects that underwent unplanned open reduction versus those that did not are described in Table 1. Indications for unplanned open reduction included irreducibility of the fracture fragments (25/27, 93%), or a change in vascular status after the reduction (2/27, 7%). Among the irreducible fractures, surgical exploration revealed fracture irreducibility was due to fracture instability (10/25, 40%), brachialis interposition (9/25, 36%), periosteal interposition (4/25, 16%), or triceps interposition (2/25, 8%). Entrapment of the neurovascular structures was identified in all cases (2/2) in which a change in vascular status occurred following the initial fracture reduction.

In the univariate analysis, age at surgery [$p=0.0165$], direction of displacement [$p<0.0001$], and gender [$p=0.0047$] were significantly related to risk of unplanned open reduction.

Although not statistically significant [$p=0.0940$], there was substantial variability in the yearly rate of unplanned open reduction during the course of the study (see Figure 2) and thus, was included in the final model as a potential confounding variable. Attending surgeon, time from injury diagnosis to surgery, weight percentile, location of initial referral, and the presence of a concomitant fracture were not significantly associated with risk of open reduction in the univariate analysis (Table 1).

The final multivariable model included the following: direction of displacement, year of surgery, age at surgery, gender and the interaction between gender and year of surgery. Direction of displacement was significantly [$p=0.0001$] related to risk of unplanned open reduction. Relative to posterior extension fractures, the risk of unplanned open reduction was significantly increased in flexion [Risk Ratio flexion vs. posterior extension fractures: 34.1, 95% CI: 8.1 to 143.6, $p<0.0001$] and posterolateral extension fractures [Risk Ratio posterolateral vs. posterior: 6.0, 95% CI: 1.3 to 27.5, $p=0.0221$]. To facilitate the interpretation of these estimates, we calculated the probability of open reduction based on gender and direction fracture displacement (see Table 2). There was a significant interaction between age and gender [$p=0.0458$]. This suggested that the relationship between age and risk of unplanned open reduction was significantly dependent upon gender. Among females, there was a 34% increase in risk of open reduction for every 1 year increase in age [Risk Ratio (RR) per 1 year increase in Age: 1.3, 95% CI: 1. to 1.7, $p=0.0139$]. Among males, age was not significantly related to risk of unplanned open reduction [Risk Ratio per 1 year increase in Age: 0.97, 95% CI: 0.8 to 1.1, $p=0.6253$]. Surgery year was not significantly associated with risk of open reduction [$p=0.4704$].

Missing Data

The distribution of demographics among the subjects excluded due to missing radiographs as compared to subjects included in the study with complete radiographic data is described in Table 3. There was no difference [$p>0.05$] in gender, age, weight, or rate of conversion to open reduction among subjects with complete radiographic data as compared to those with incomplete radiographic data. There was a significant association between missing radiographs and time. For every one year increase in time, the odds of a subject presenting with missing radiographic information decreased by 14% [95% CI: 8 to 19%, $p<0.0001$]. This indicated that subjects that presented later in the study period were more likely to have complete radiographic data.

Discussion

Closed reduction and percutaneous fixation is currently the accepted treatment methodology for supracondylar humerus fractures in children [7, 8, 12, 21]. In the present study, >90% of all fractures were managed by closed reduction. Across the entire study period, the overall incidence of conversion from closed to open reduction (7%) was similar to open reduction rates (1 to 46%) reported in related studies [12–18, 22]. Comparisons of open reduction rates across studies, however, is challenging due differences in inclusionary criteria. We limited our study population to closed, type III fractures that were undergoing planned closed reduction and percutaneous pinning. In this way, the rate of unplanned open reduction in our

study tended to be higher than the rate of open reduction reported in studies that included all supracondylar fractures and lower than the rate of open reduction reported in studies that included fractures undergoing planned open reduction in their respective cohorts.

Indications for open reduction in current literature include open injury [11], compartment syndrome [10], a vascular disruption with a pulseless or poorly perfused hand [9], and/or failure to obtain stable anatomic alignment by closed reduction methods. Irreducible fractures are often the result of brachialis muscle entrapment [17, 23, 24]. Archibeck *et al.* [24] reported brachialis interposition was present in 90% of the irreducible cases. Reitman *et al.* [13] reported that 43% of irreducible fractures that underwent open reduction were associated with brachialis interposition. Among the irreducible fractures in the current study (n=25), surgical exposure revealed that the many of cases were associated with interposition of soft-tissue structures such the brachialis (n=9), triceps (n=2) and/or periosteum (n=4) within the fracture fragments. However, the most common factor (n=10) attributed to an inability to obtain a successful closed reduction was the positioning of the fracture fragments. The majority of the cases in our study underwent surgery prior to the development of a novel technique for reducing multidirectional fracture patterns in which the distal fragment is unstable in flexion and extension [25]. It is possible that the application of this treatment technique [26] to these cases may help to decrease the need for unplanned open reduction in the future.

Vascular compromise is a factor frequently cited as a reason for open reduction. Reitman *et al.* [13] reported that 24% of fractures requiring open reduction were associated with vascular compromise. The rate of open reduction due to vascular concerns in the current study, 7%, was lower than rates reported in current literature. This potentially reflects the fact that we excluded patients that underwent a planned open reduction due to vascular concerns prior to surgery. Thus, the rate of open reduction due to vascular concerns represents the proportion of patients that underwent a planned CRPP, demonstrated a change in vascular status following reduction and subsequently underwent open reduction and surgical exploration.

The appearance of the fracture on the pre-operative radiographs is an appealing predictor of the risk of open reduction as this variable could be used to guide surgical decision making. We observed a strong relationship between flexion as well as posterolateral extension patterns and the risk of open reduction. These observations are consistent with related studies in current literature. Mahan *et al.* [4] reported lower rates of open reduction in extension type III fractures (11%) when compared to flexion type fractures (39%). Although not explicitly tested, Reitman *et al.* [13] noted that a large percentage of irreducible fractures (25/46) that required open reduction were displaced in a posterolateral direction. Posterolaterally displaced fractures have also been reported to be multidirectionally unstable [26], have a higher risk for neurovascular deficit and thus, more likely to require open reduction [13]. Beck *et al.* [27] reported that initial fracture displacement was a strong risk factor for open treatment. However, in contrast to the current study, direction of displacement (lateral vs. anteroposterior) was not predictive of need for open reduction. The comparability of these results to the current study is questionable as the investigators failed to differentiate between flexion and extension type fractures, included type II fractures in the

analysis and, as acknowledged in the limitations section, the authors reported that the more complex fracture patterns were sent to pediatric-trained orthopaedic surgeons.

Although non-significant, the proportion of fractures that underwent open reduction varied considerably by year. Further review of the data suggests that the fluctuation in the yearly open reduction rate was likely driven by yearly changes in the proportion of flexion type fractures, a factor strongly related to the risk of open reduction (Figure 2). We also observed a significant relationship between age, gender and risk of open reduction. Among females, for every one year increase in age, the risk of open reduction increased by 48%. This same trend was not observed in males. We suspect this finding may be related to the fact that for unknown reasons, flexion fractures tended to occur in older females. Differences in ossification patterns as well as the initial mechanism of injury males compared to females may also contribute to this trend. Inconsistent findings have been reported regarding the association between age and need for open reduction in current literature. Beck *et al* [27] reported that age was not an independent risk factor for close reduction failure. In contrast, Fletcher *et al* [28] reported a higher rate of open reduction in patients older than 8 years old compared to patients younger than 8 years. The authors suggested that older patients may be more likely to require open reduction due to their association with higher energy mechanisms of energy compared to younger populations. Future research is needed to better understand gender specific characteristics of supracondylar fractures that increase severity of injury and increase risk of open reduction.

The strengths of the current study include the large study population, and the study cohort which was restricted to fractures that undergoing planned closed reduction. This study was limited by the large proportion of subjects that did not have pre-operative radiographs available for review. However, comparison of demographics and clinical characteristics among subjects with missing radiographs versus those with radiographs revealed the two groups were very similar. Study year was inversely associated with odds of missing radiographs. We believe this association was due to quality initiative efforts at our institution aimed at improving documentation of supracondylar fractures, a factor that is unlikely to be related to the conversion from closed to open reduction. Furthermore, documentation of time of injury was not consistently available in the subjects' charts and thus, we used time of diagnosis (time stamp on initial radiograph) as a surrogate for time of injury. Consequently, we were not able to directly evaluate the relationship between time from injury to surgery and the risk of conversion from closed to open reduction. Finally, due to the retrospective nature of the data collection procedures, it was not possible to confirm the anatomical factors responsible for closed reduction failure. Prospective studies with more deliberate data collection procedures may allow for a more accurate assessment of anatomical factors that prevent a successful closed reduction.

Conclusion

Current literature does not systematically define risk factors associated with open reduction in the treatment of SCHF. We aimed to identify factors predictive of the need for unplanned open reduction among children undergoing planned closed reduction and percutaneous pinning of completely displaced supracondylar humerus fractures. Direction of fracture

displacement was the strongest predictor of unplanned open reduction in both the univariable and multivariable analyses. Relative to posterior extension displaced fractures, the risk of unplanned open reduction was significantly increased among flexion as well as posterolateral extension fractures. Given the observed relationship between fracture displacement and risk of unplanned open reduction, the direction of displacement of the supracondylar humerus fracture should be taken into account during pre-operative surgical planning.

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Figure 1.
Summary of Subject Enrollment

Figure 2.
Changes in Incidence of Open Reduction and Percentage of Flexion Type Fractures Across the Study Period

Table 1

Demographics and Clinical Characteristics

	Closed Reduction (N = 357)		Open Reduction (N = 27)		pvalue
Referral from Outside Hospital					
Yes	184	93.9%	12	6.1%	0.2932
No	140	90.9%	14	9.1%	
Gender					
Female	180	95.2%	9	4.8%	0.0047
Male	178	87.7%	25	12.3%	
Year					
04–05	40	93.0%	3	7.0%	0.0940
05–06	34	97.1%	1	2.9%	
06–07	32	97.0%	1	3.0%	
07–08	42	95.5%	2	4.5%	
08–09	42	91.3%	4	8.7%	
09–10	54	94.7%	3	5.3%	
10–11	48	96.0%	2	4.0%	
11–12	65	85.5%	11	14.5%	
Concomitant Fracture					
No	339	93.1%	25	6.9%	0.4117
Yes	18	90.0%	2	10.0%	
Direction of Displacement					
Flexion	15	50.0%	15	50.0%	<.0001
Posterolateral Extension	90	92.8%	7	7.2%	
Posteromedial Extension	88	96.7%	3	3.3%	
Posterior Extension	164	98.8%	2	1.2%	
Time to Surgery					
<12 hrs.	136	91.9%	12	8.1%	0.3671
12–24 hrs.	182	93.8%	12	6.2%	
>24 hrs.	20	100.0%	0	0.0%	

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Surgeon Group	Closed Reduction (N = 357)		Open Reduction (N = 27)		pvalue
	N	Mean	%	Stdev.	
A	25	89.3%	3	10.7%	0.7334
B	45	91.8%	4	8.2%	
C	37	94.9%	2	5.1%	
D	22	88.0%	3	12.0%	
E	49	98.0%	1	2.0%	
F	55	94.8%	3	5.2%	
G	41	91.1%	4	8.9%	
H*	83	92.2%	7	7.8%	
Age at Surgery	5.9	2.5	7.1	2.8	0.0165
Weight Percentile	53.9	29.4	60.0	32.7	0.3065

* Surgeons that performed <25 surgeries were grouped together into a single category

Table 2

Probability of Open Reduction

	Probability	95% CI
Female *		
Posterior	0.3%	0.1 to 1.9%
Posteromedial	0.7%	0.1 to 3.8%
Posterolateral	2.1%	0.5 to 7.6%
Flexion	21.7%	7.3 to 49.4%
Male *		
Posterior	2.0%	0.5 to 7.9%
Posteromedial	4.6%	1.4 to 13.8%
Posterolateral	12.1%	5.7 to 23.8%
Flexion	64.3%	40.5 to 82.6%

* Probability estimates calculated at the median age (6 years) and median study year (2008)

Table 3

Missing Radiographs

		Complete Radiographic Data		Missing Radiographs	
		N=384		N=403	
Gender					
Female	186	48.4%	207	52.7%	0.4117
Male	198	51.6%	196	49.7%	
Procedure					
Closed Reduction	357	48.4%	387	52.0%	0.0589
Open Reduction	27	48.4%	16	37.2%	
Year					
2004	43	48.4%	48	52.7%	<0.0001
2005	35	51.6%	46	56.8%	
2006	33	0.0%	64	66.0%	
2007	44	93.0%	59	57.3%	
2008	46	7.0%	59	56.2%	
2009	57	0.0%	56	49.6%	
2010	50	11.2%	48	49.0%	
2011	76	9.1%	23	23.2%	
Age [yrs.]	6.0	±2.5	6.0	±2.4	0.7353
Weight [kg]	22.2	±8.0	22.1	±8.5	0.9412