The Role of Closed Reduction in the Treatment of Pediatric Monteggia Fractures

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Introduction: Previous ulnar-based treatment algorithms for pediatric Monteggia fractures advocate for treating incomplete ulnar fractures with closed reduction and casting (CRC) while treating complete fractures surgically. However, recent evidence has suggested that these algorithms may result in overtreatment. This study aimed to evaluate the outcomes of CRC treatment across all ulnar fracture patterns and identify factors associated with CRC failure.

Methods: A retrospective study was conducted of patients treated for Monteggia fractures at a single institution from 2002 to 2022. Inclusion criteria were patients younger than 18 at the time of injury, with complete radiographic follow-up from pre-intervention until the time of bony union. Patients treated surgically without a trial of CRC due to an open fracture or delayed presentation for treatment were excluded. Patient demographics, radiographs, and relevant surgical records were analyzed.

Results: Eighty patients, 34 (42.5%) males, were included. Sixty-seven (83.8%) had complete ulnar fractures. The average age at injury was 5.7 years (range: 2 to 17), and the average follow-up was 5.6 months (range: 1 to 71). Fifty-eight (72.5%) patients were successfully treated with CRC. Of the 22 (27.5%) failures, all but 1 required surgery. Older age at injury was a risk factor for CRC failure ($P = 0.002$). Failure occurred in 50% of patients older than 6 and 17.9% of patients ages 6 or younger ($P = 0.003$). Other ulna-related criteria, including Bado classification, fracture pattern, and ulnar displacement, were not significant risk factors.

Conclusion: This study's results support an emerging body of evidence suggesting that ulnar-based algorithms may overpredict CRC failure in pediatric Monteggia fractures. A trial of CRC in these fractures, regardless of ulnar fracture pattern, may prevent unnecessary surgical intervention. In this study, 26.3% of patients ultimately required surgery following an initial trial of CRC, whereas previous algorithms would have recommended surgery in 83.8% of patients. However, patients older than 6 may be less likely to retain reduction with CRC, as our study showed that 50% required surgical treatment.

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Monteggia fractures comprise only 1.5% to 3% of pediatric elbow injuries.[1,2] Early recognition and appropriate treatment are essential, as missed Monteggia fractures can lead to chronic pain, elbow instability, and functional impairment.[3–5] Monteggia fractures were initially defined as fractures in the proximal 1/3 of the ulna with an anterior dislocation of the radial head when characterized by Giovanni Battista Mongteggia in 1824.[3,6] Over time, that definition expanded to include ulna fractures with radial head dislocations in other directions or with associated radial head fractures.[3] The Bado classification is often used to characterize Monteggia fractures.[1,2]

Due to variations in fracture patterns and injury recovery, treatment of Monteggia fractures differs between pediatric and adult patients.[3,6,7] While surgical intervention is typical for adults, pediatric cases are predominantly managed nonoperatively with closed reduction and casting (CRC).[6,8–10] Nonetheless, CRC is estimated to fail in 20% to 30% of pediatric patients.[11–13] Complete ulnar fractures exhibit a higher propensity for treatment failure. It has been previously estimated that up to 33% of complete ulnar fractures fail CRC.[10,11,14] Previously proposed treatment algorithms recommended CRC for incomplete fractures, such as greenstick fractures and plastic deformation, while advocating for surgical treatment of complete fractures.[10,12,15]

However, recent evidence has suggested that these treatment algorithms may result in unnecessary operative interventions. In a single-center study of 94 patients with complete ulna fractures, 83% were successfully treated nonoperatively utilizing variations of casting depending on Bado type I to IV.[16] Among those that failed nonoperative management, 9 failed reduction in the emergency department (ED), and 7 lost reduction after CRC. This study implied that many pediatric Monteggia fractures may be treated successfully with CRC and careful monitoring.

The conflicting evidence in the literature regarding the optimal treatment algorithm for pediatric Monteggia fractures highlights the need for further exploration of risk

factors for failure of nonoperative treatment. This study aims to characterize the outcomes of CRC treatment for pediatric Monteggia fractures and identify risk factors for treatment failure.

METHODS

Following Institutional Review Board approval, ICD-9 and ICD-10 codes were utilized to identify patients with Monteggia fractures. Data was retrospectively collected on patients treated at a single institution between January 2002 and December 2022. Included patients were younger than 18 years of age at the time of injury with accessible radiographs from preintervention, postintervention, and at the time of radiographic healing. Exclusion criteria included Monteggia equivalents in which patients had radial head fractures but no radiocapitellar dislocation and patients who underwent surgical fixation without a trial of CRC due to having an open fracture or delayed presentation for treatment. Open fractures that were treated with irrigation and debridement without fixation were eligible for inclusion.

Electronic medical records were used to collect data on relevant patient demographics, preintervention and postintervention radiographs, casting techniques, mechanism of injury, and relevant surgical records. Nonoperative management included CRC under conscious sedation in the ED by residents or fellows or CRC under sedation in the operating room (OR) for patients unable to achieve congruent radiocapitellar alignment in the ED. The reduction maneuver was axial traction and correction of the coronal plane deformity, followed by supination and elbow flexion. Patients were placed in forearm supination and elbow flexion (100 degrees) for Bado 1 and 3 and forearm pronation and relative elbow extension (20 to 30 degrees of flexion) for Bado 2. Typically, bivalveded long-arm fiberglass casts were used. Postreduction radiographs were obtained to ensure adequate reduction. Patients were typically seen weekly for the first 3 weeks with radiographic surveillance and then followed radiographically until full fracture union and clinically until the full return of function. CRC failure was defined as subluxations or dislocations of the radial head or loss of ulnar reduction during follow-up, as described in the previously proposed conservative model. Patients who maintained a reduction of the ulna and radial head throughout the follow-up period were considered successful.[12] Patients who failed nonoperative treatment were treated with open reduction and internal fixation (ORIF) with K-wires, plates and screws, or intramedullary nail (IM) fixation with flexible nails. Patients were treated by fellowship-trained orthopaedic surgeons, and treatment was at the surgeons' discretion.

TABLE 1. Patient Demographics and Fracture Characteristics

N = 80 patients	(n/N [%])
Age at injury (y)	5.7 (range: 2-17)
Male sex	34 (42.5)
Mechanism of injury	
Fall	75 (93.8)
Tackled	2 (2.5)
Motor vehicle collision	3 (3.8)
Ulnar displacement	
Nondisplaced	34 (42.5)
< 1 cortical diameter	31 (38.8)
> 1 cortical diameter	15 (18.8)
Bado classification	
I	53 (66.3)
II	4 (5.0)
III	10 (12.5)
IV	13 (16.3)
Open vs. closed fracture	
Closed	76 (95.0)
Open	4 (5.0)
Location of ulnar fracture	
Proximal	45 (56.3)
Mid	35 (43.8)
Distal	0
Fracture pattern	
Incomplete	13 (16.3)
Plastic	2 (2.5)
Greenstick	7 (8.8)
Buckle	4 (5.0)
Length stable	39 (48.8)
Transverse	16 (20.0)
Short oblique	23 (28.7)
Length unstable	28 (35.0)
Long oblique	11 (13.8)
Comminuted	15 (18.8)
Spiral	2 (2.5)
Maximum ulnar angulation at injury [mean (SD)]	18.37 ± 15.21

Ulnar fractures were categorized as incomplete (plastic, greenstick, or buckle), length stable (transverse or short oblique), and length unstable (long oblique, comminuted, or spiral). When considering ulnar displacement, cortical diameter was defined as the width of the bone from cortex to cortex at the level of the fracture. Angulation was measured on anteroposterior and lateral radiographs at 3 timepoints: preintervention, immediately following reduction, and at the time of union. Healing was defined as bridging callus formation in at least 3 of 4 cortices on follow-up radiographs.[17,18]

Statistical Analysis

Univariate analysis was performed on categorical and continuous data to identify variables associated with CRC failure. Categorical data were analyzed using Fisher exact or χ^2 tests and represented with frequencies and percentages. Appropriate parametric and nonparametric measures were utilized for continuous data (independent Student t test). A logistic regression model was used to establish risk factors for CRC failure. Statistical significance was set at 0.05. Statistical analysis was performed on IBM SPSS Statistics Version 28.0 (IBM Corporation, Armonk, NY).

RESULTS

One hundred seven patients with Monteggia fractures were identified. Twenty-seven patients had primary surgical fixation due to an open fracture or delayed presentation and were excluded from the study. The 80 remaining patients met the criteria for this study. Thirty-four (42.5%) patients were male. The average age at the time of injury was

FIGURE 1. Preintervention, postreduction, and postoperative radiographs from a 10-year-old with a Bado I Monteggia fracture that lost reduction following treatment with closed reduction and casting. A, Prereduction AP radiograph. B, Prereduction lateral radiograph. C, AP radiograph following reduction with CRC. D, Lateral radiograph immediately following reduction with CRC showing loss of reduction and subluxation of radiocapitellar joint. E, AP radiograph postoperative fixation. F, Lateral radiograph postoperative fixation showing well-aligned radiocapitellar joint.

5.7 years (range: 2 to 17). Fracture characteristics are depicted in Table 1. Four open fractures were treated with CRC following irrigation and debridement of the wound: 2 were treated in the OR and 2 in the ED. Eight closed fractures were brought to the OR for CRC under anesthesia.

Treatment with CRC failed in 22 (27.5%) patients. Of those, 10 (12.5%) fractures were irreducible with CRC and treated operatively; 7 had closed treatment of the dislocation and open fixation of the ulnar fracture, while 3 had open reduction of the radiocapitellar joint. The remaining 12 (15%) patients achieved reduction with CRC but subsequently lost reduction during follow-up (Fig. 1). Three of those patients had been initially treated in OR for CRC under anesthesia The average time to loss of reduction was 10.6 days (range: 1 to 20).

Treatment for the 22 failures included: 17 (77.2%) treated with IM nailing, 3 (13.6%) with ORIF (2 with plate and screws and 1 with intramedullary K-wire), 1 (4.5%) with closed reduction and percutaneous pinning (CRPP), and 1 (4.5%) with a second round of CRC. One patient was treated with IM nailing after failing to obtain initial reduction with CRC and later experienced a redislocation of the radial head treated with plates and screws. There were no cases of nonunion. The average time to radiographic healing was 7.9 (range: 3 to 33) weeks. The average length of immobilization following successful CRC for 56 patients with available data was 5.3 weeks (range 3.4 to 9.4). The average follow-up was 5.6 months (range: 1 to 71). Treatment outcomes are depicted in Table 2.

TABLE 2. Treatment Types and Outcomes

	[n/N (%)]
Maximum ulnar angulation after initial treatment [mean (SD)]	6.34 ± 5.89
Closed reduction successful[+]	
Yes	58 (72.5)
No	22 (27.5)
Treatment after failure	
Repeat CRC	1 (4.5)
ORIF	3 (13.6)
CRPP	1 (4.5)
Intramedullary fixation	17 (77.3)
Maximum ulnar angulation at healing* [mean (SD)]	6.03 ± 4.28
Time to full healing (wk) [mean]	7.9 (range: 3-33)
Average length of follow-up (mo)	5.6 (range: 1-71)

*Callus formation in at least 3 of 4 cortices on radiographs.

CRC indicates closed reduction and casting; CRPP, closed reduction and percutaneous pinning; ORIF, open reduction and internal fixation.

TABLE 3. Success of CRC Versus Categorical Variables

	Success (n 58), [n/N (%)]	Failure (n 22), [n/N (%)]	*P*
Sex			0.09
Male	28 (82.4)	6 (17.6)	
Female	30 (65.2)	16 (34.8)	
Age at Injury			**0.003**
≤ 6 y	46 (82.1)	10 (17.9)	
> 6 y	12 (50)	12 (50)	
Bado classification			0.1
I, II, III	51 (76.1)	16 (23.9)	
IV	7 (53.8)	6 (46.2)	
Location of ulnar fracture			0.85
Proximal	33 (73.3)	12 (26.7)	
Mid	25 (71.4)	10 (28.6)	
Distal	0	0	
Fracture pattern			0.564
Incomplete	10 (76.9)	3 (23.1)	
Plastic	1 (50.0)	1 (50.0)	
Greenstick	6 (85.7)	1 (14.3)	
Buckle	3 (75.0)	1 (25.0)	
Length stable	26 (66.7)	13 (33.3)	
Transverse	11 (68.8)	5 (31.3)	
Short oblique	15 (65.2)	8 (34.8)	
Length unstable	22 (78.6)	6 (21.4)	
Long oblique	8 (72.7)	3 (27.2)	
Comminuted	13 (86.7)	2 (13.3)	
Spiral	1 (50.0)	1 (50.0)	
Ulnar Displacement			0.089
Nondisplaced	28 (84.8)	5 (15.2)	
Displaced ≤ 1 cortical diameter	21 (65.6)	11 (34.4)	
Displaced > 1 cortical diameter	9 (60)	6 (40)	

Statistical significance ($P < 0.05$) values are in bold.

Factors Correlated With CRC Failure

When evaluating categorical variables (Table 3) for predictors of treatment failure, sex, Bado classification, and fracture location did not demonstrate statistical significance. Overall, 15 of the 22 failures had fractures that were complete and displaced. Notably, failure rates did not significantly differ between ulnar fracture patterns, with 3 (23.1%) incomplete fractures, 19 (28.4%) complete fractures [13 (33.3%) length stable complete fractures and 6 (21.4%) length unstable complete fractures] failing to maintain reduction, ($P = 0.564$). When evaluating continuous variables (Table 4), the maximum ulnar angulation in any plane at the time of injury was not significantly different between those treated successfully and those who failed; 16.8 ± 13.7 versus 22.4 ± 18.5, ($P = 0.208$). The maximum ulnar angulation immediately following initial treatment also did not show statistically significant differences between failures and those treated successfully; 6.8 ± 5.9 versus 6.0 ± 5.9, ($P = 0.422$). A subanalysis (Table 5) was conducted to compare fracture characteristics of 10 irreducible fractures and the 12 that lost reduction following initial successful CRC. No significant differences in fracture characteristics between these 2 groups were found.

Age Stratification of Patients

Analysis of age as a continuous variable revealed a significant distinction: patients successfully treated with CRC were younger on average than those who failed CRC, 5.2 ± 1.7 versus 7.2 ± 3.0 ($P = < 0.001$). Following univariate analysis, classification and regression tree (CART) was used to identify optimal splits for predicting CRC failure in continuous variables. Age more than 6 was identified as an optimal split for age at the time of injury. Notably, when considering age as a categorical variable, patients ages 6 years and older exhibited a statistically significant higher rate of CRC failures, with 12 (50%) patients older than 6 failing treatment with CRC compared with 10 (17.9%) patients ages 6 or younger, ($P = 0.003$).

Considering all pertinent variables, a multivariate regression model was created (Table 6). This model identified older age at the time of injury as being the only factor associated with an increased risk for CRC failure [OR: 1.7 (95% CI: 1.2-2.2), $P = 0.002$]. Fracture pattern, sex, Bado classification, maximum ulnar angulation, and location of the ulnar fracture were not significant risk factors.

DISCUSSION

Nonoperative management of pediatric Monteggia fractures has long been the preferred treatment method.[19,20] This study, utilizing a conservative approach towards treatment found that CRC was successful in 72.5% of patients, and only 15% of patients lost reduction following initial correction with CRC. However, several previous studies advocated for surgical treatment in patients with complete ulnar fractures.[10,12,15] Ring and Waters[10,15] first proposed an ulnar-based treatment algorithm that suggested CRC for incomplete fractures (greenstick and plastic), IM fixation for length-stable complete fractures (transverse and short oblique), and ORIF for length-unstable complete fractures (long oblique and comminuted). Ramski et al[12] affirmed this algorithm in a cohort of 112 fractures. They reported a failure to

TABLE 4. Success of CRC Versus Continuous Variables

	Success (n 59)	Failure (n 21)	*P*
Age at injury (y) [mean (SD)]	5.18 ± 1.70	7.22 ± 3.00	**< 0.001**
Maximum ulnar angulation in any plane at injury	16.82 ± 13.66	22.43 ± 18.45	0.208
Maximum ulnar angulation in any plane following initial treatment	6.75 ± 5.91	5.98 ± 5.94	0.422
Maximum ulnar angulation in any plane at time of radiographic healing	7.02 ± 6.82	3.43 ± 5.75	**0.004**

Statistical significance ($P < 0.05$) values are in bold.

TABLE 5. Comparison of Irreducible Fractures Versus Later Failures

	Irreducible (n 10) [n/N (%)]	Failed after initial reduction (n 12) [n/N (%)]	*P*
Sex			0.162
Male	1 (16.7)	5 (83.3)	
Female	9 (56.3)	7 (43.8)	
Age at injury			0.691
≤ 6 y	4 (40)	6 (60)	
>6 y	6 (50)	6 (50)	
Bado classification			0.646
I, II, III	8 (50)	8 (50)	
IV	2 (33.3)	4 (66.7)	
Location of ulnar fracture			0.391
Proximal	4 (33.3)	8 (66.7)	
Mid	6 (60)	4 (40)	
Distal	0	0	
Fracture pattern			0.841
Incomplete	2 (66.7)	1	
Plastic	1 (50.0)	1 (50.0)	
Greenstick	6 (85.7)	1 (14.3)	
Buckle	3 (75.0)	1 (25.0)	
Length stable	5 (38.5)	8 (61.5)	
Transverse	11 (68.8)	5 (31.3)	
Short oblique	15 (65.2)	8 (34.8)	
Length unstable	3 (50)	3 (50)	
Long oblique	8 (72.7)	3 (27.2)	
Comminuted	13 (86.7)	2 (13.3)	
Spiral	1 (50.0)	1 (50.0)	
Ulnar displacement			0.296
Nondisplaced	4 (80)	1 (20)	
Displaced ≤ 1 cortical diameter	4 (36.4)	7 (63.6)	
Displaced >1 cortical diameter	2 (33.3)	4 (66.6)	
Age at injury (y) [mean (SD)]	7.48 ± 3.83	7.00 ± 2.26	0.875
Maximum ulnar angulation in any plane at injury	17.47 ± 18.89	26.57 ± 17.80	0.101

TABLE 6. Regression Model for Success of CRC

	Odds ratio (95% CI)	*P*
Age at injury (y)	1.66 (1.19-2.29)	**0.002**
Sex		
Male	Reference	0.068
Female	3.36 (0.91-12.33)	
Max angulation at injury	1.02 (0.98-1.06)	0.365
Bado classification		
I, II, III	Reference	0.288
IV	2.20 (0.51-9.45)	
Location of ulnar fracture		
Proximal	Reference	0.835
Mid	0.88 (0.26-2.97)	
Fracture pattern [n/N (%)]		
Incomplete	Reference	
Plastic		
Greenstick		
Buckle		
Length stable	1.20 (0.20-7.39)	0.841
Transverse		
Short oblique		
Length unstable	0.56 (0.08-3.91)	0.557
Long oblique		
Comminuted		
Spiral		

maintain the reduction in 19% of complete fractures treated with CRC. No failures occurred in patients treated in accordance with the recommended algorithm. They concluded that complete ulnar fractures treated with CRC are at risk for recurrent instability and recommended all complete fractures be treated operatively.

More recently, it has been suggested that this treatment strategy may be too aggressive as it recommends surgery without a trial of CRC for most patients.[16,21,22] In the original study by Ring and Waters, 50% of patients were treated surgically with the ulnar-based approach. In the Ramski study, 63% of patients had complete fractures and were recommended for surgery without a trial of CRC. However, a recent study of 89 pediatric Monteggia fractures and variants by Haft et al[22] noted that complication rates were significantly higher in patients treated operatively (40% vs. 9.4%), with loss of range of motion being the most common complication. They recommended a trial of initial nonoperative management, particularly for displaced Monteggia variants. The present study utilized a conservative approach that did not use an ulnar-based algorithm. The results of this study demonstrated that CRC may be a more successful treatment method for displaced pediatric Monteggia fractures than previously reported, with 72.5% of patients avoiding fracture fixation. Only 12.5% of patients failed an initial attempt at CRC while 15% lost reduction. This suggests that if adequate reduction is obtained with CRC, the probability of failure is low. This study found that failure rates did not vary based on fracture pattern. Finally, the findings suggest that patients age 6 and younger generally have success with CRC, while those older than 6 are more susceptible to CRC failure.

Several more recent studies have also challenged this ulnar-based approach. Our study was most similar to that conducted by Foran et al.[16] In their study, all closed Monteggia fractures without signs of compartment syndrome or nerve compromise were treated with an attempted CRC. They reported a failure rate of 17% (16) in 94 fractures treated with CRC. CRC was considered unsuccessful if an initial reduction was not obtained with CRC (9 patients) or if the reduction was lost following a successful initial CRC (7 patients). However, unlike the current study, they only considered patients treated in the ED and excluded those treated with CRC in the OR. In another study, Hart et al[21] compared the outcomes of 37 complete ulnar fractures treated surgically to 36 complete fractures treated with CRC. They found that only 13.9% (5) of complete fractures failed to maintain reduction following CRC and required operative treatment. Notably, they did not include irreducible fractures in their analysis of failure. A case series by Leonidou et al[23] of 40 Monteggia fractures treated with CRC, regardless of fracture pattern, reported that CRC was successful in 80% of patients. The results of our study support these prior findings that most complete fractures can be successfully

treated with CRC, with 78.6% of length-unstable being successfully treated with CRC.

Despite growing evidence that an ulnar-based algorithm does not accurately predict CRC failure, there are inconsistencies in the literature regarding factors predictive of failure. This study found that age at injury, but not Bado type or ulnar angulation, is a risk factor for CRC failure. This varies slightly from the risk factors reported in other studies. Hart et al[21] found Bado type III or IV to be a risk factor for CRC failure. Foran et al[16] reported higher failure rates in Bado type II or III fractures and fractures with ulnar angulation $\geq$36.5 degrees. Given the variation in these findings, future studies with larger cohorts and more robust methodologies are needed to better evaluate risk factors for CRC failure in pediatric Monteggia fractures.

This study has several limitations. The retrospective design limits the ability to control for confounding variables and increases the risk of selection bias. The use of a single institution limits the generalizability of these results and may introduce bias related to treatment protocols and surgeon experience. With an average follow-up of 22 weeks, this study presents an analysis of short-term outcomes but cannot draw conclusions about the long-term results of CRC in this patient population. However, all patients were followed until radiographic union, following which further loss of reduction would not be expected. While we determined older age to be a risk factor for failure, only 1 patient was older than 10 years at the time of injury. Finally, this study reports radiographic results only. Due to inconsistencies in the medical record, analysis of intraoperative data, such as entrapment of the annular ligament, could not be reported. Further studies are needed to determine functional outcomes in patients treated with CRC.

In conclusion, this study supports the emerging body of evidence that ulnar-based algorithms may overpredict CRC failure in pediatric Monteggia fractures. In this cohort, 27.5% of patients ultimately required surgical treatment after initial treatment with CRC. However, only a 15% loss reduction following the initial successful CRC. If the ulnar-based approach had been used, 84% of patients would have been treated operatively. These findings support a more conservative approach toward Monteggia fractures that may prevent unnecessary surgical procedures. Moreover, the results of this study suggest that patients older than 6 years of age may be more susceptible to CRC failure. These patients may need closer follow-up and a lower threshold for operative management.

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