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Original Research

Risk Factors for Failed Closed Reduction of Pediatric Distal Radius Fractures

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Purpose: Distal radius fractures (DRFs) are common pediatric injuries typically treated with closed reduction and casting. A substantial number of these fractures fail nonsurgical management, occasionally requiring surgical intervention. Risk factors associated with an unsuccessful initial closed reduction (UIR) attempt or loss of reduction (LOR) after a successful closed reduction remain poorly characterized.
Methods: This was a retrospective investigation of pediatric patients with displaced DRFs treated by closed reduction and casting at a single children's hospital from 2013 to 2017. Patient factors (age, sex, and body mass index) and radiographic measurements (fracture type, fracture displacement, associated ulna fracture, and cast index) were evaluated to determine risk factors for UIR and LOR.
Results: We identified 159 children (118 boys, mean age, 11 ± 3 years) with DRFs who underwent closed reduction and casting. An initial acceptable reduction was achieved in 81% of patients, and LOR occurred in 21.7%. Higher initial fracture translation in the sagittal or coronal plane and higher initial angulation in the coronal plane were associated with higher fluoroscopy times. Higher initial translation in the sagittal plane was independently associated with UIR. After closed reduction, residual translation in the sagittal plane and cast index were independent predictors for LOR. Fractures that were completely displaced in the sagittal plane were 6.2 times less likely to undergo an acceptable initial reduction, and fractures with any residual postreduction translation in the sagittal plane were 4.7 times more likely to demonstrate LOR.
Conclusions: The most important factors predicting failure of nonsurgical management of pediatric DRFs are translation in the sagittal plane and cast index greater than 0.80. To optimize patient outcomes, these variables should be recognized by the treating provider and emphasized during simulation training of orthopedic and plastic surgery residents.
Type of study/level of evidence: Prognostic III.

Distal radius fractures (DRFs) are the most common fracture in the pediatric population, with a peak incidence in children aged 5 to 14 years.[1,2] Although these fractures represent one of the most common reasons for orthopedic surgical intervention in a child, most of cases are managed nonsurgically with satisfactory outcomes.[3] The standard of care in the nonsurgical management of displaced DRFs is immobilization and closed reduction as indicated to improve fracture alignment and permit adequate healing, although the precise definition of acceptable alignment remains controversial.[3,4]

One of the most common complications after the closed reduction and casting of displaced DRFs is redisplacement or loss of reduction (LOR) of the fracture, which occurs in 21% to 46% of patients and may necessitate repeat closed reduction or surgical intervention.[5–7] Given the high rate of redisplacement after closed reduction, understanding the risk factors for this phenomenon is critical to optimize the nonsurgical care of these injuries.

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Furthermore, some authors have advocated for initial surgical intervention for high-risk DRFs in an effort to minimize the number of patients who require remanipulation or develop a malunion.[8–10] However, this strategy necessitates (1) a clear, evidence-based definition of which factors constitute high risk, and (2) the determination of what threshold of risk warrants surgical intervention.

Unfortunately, specific factors that portend a higher likelihood of fracture redisplacement remain a matter of debate, because several studies have been published to date with varied results. Factors linked to higher rates of redisplacement include patient age,[11] initial fracture displacement,[5,7,10–16] quality of the reduction,[5–7,11–13,15–17] cast index,[5,17,18] presence of an ipsilateral ulna fracture,[10–12,16] presence of an intact ipsilateral ulna,[7,9,19] degree of fracture comminution,[17] and distance of the fracture from the physis.[11]

Although a substantial number of investigations characterized a set of risk factors, several factors have only been partially characterized. First, it is well-described that the initial and residual (postreduction) fracture displacement has a major role in predicting outcome. However, the magnitude, type (translation vs angulation), and plane (sagittal [referring to anteroposterior (AP)] vs coronal [referring to radioulnar]) of displacement, which are most important in predicting risk for failed closed reduction, are unclear. Second, several studies demonstrated that the ability to achieve an acceptable or anatomic initial reduction has an important role in preventing LOR,[5,11,13] yet no studies examined which factors predict the difficulty of fracture reduction and/or affect the likelihood of achieving an adequate reduction. Third, there have been conflicting reports regarding the importance of ipsilateral ulna fractures and cast indices, in particular, and their effect on outcome.

Ultimately, we hypothesized that there are identifiable (and potentially modifiable) risk factors for failed closed reduction of pediatric DRFs. Thus, the aim of this study was to understand these risk factors better at a single high-volume children's hospital in an effort to determine which factors should be optimized when performing closed reductions, while adding to the existing literature that may ultimately guide initial treatment (surgical vs nonsurgical) decision-making.

Materials and Methods

Patient sample

After we obtained institutional review board approval, we performed a retrospective review of all displaced distal radius fractures in children aged 4 to 18 years who underwent closed reduction and casting at our institution between July 1, 2013 and June 30, 2017. Patients were identified using a billing query with Current Procedural Terminology codes through our electronic medical record. All reductions were performed in the emergency room of our large pediatric level I trauma center under conscious sedation. Of the patients identified, only those with closed, displaced physeal or bicortical fractures at or distal to the radial metaphyseal–diaphyseal junction were included in the study. Exclusion criteria included distal radius buckle fracture (n = 398), distal radius greenstick fracture (n = 60), open injury (n = 44), additional concomitant upper-extremity fractures other than distal ulnar fractures (n = 42), inadequate imaging (n = 35), no emergency room visit on record and/or prior reduction attempted at an outside hospital (n = 753), and insufficient follow-up (patients with less than 4 weeks of follow-up or patients not followed through fracture healing) (n = 25).

Radiographic measures

The diagnosis of a DRF was confirmed using the initial radiograph. Each included fracture was classified as a physeal fracture or

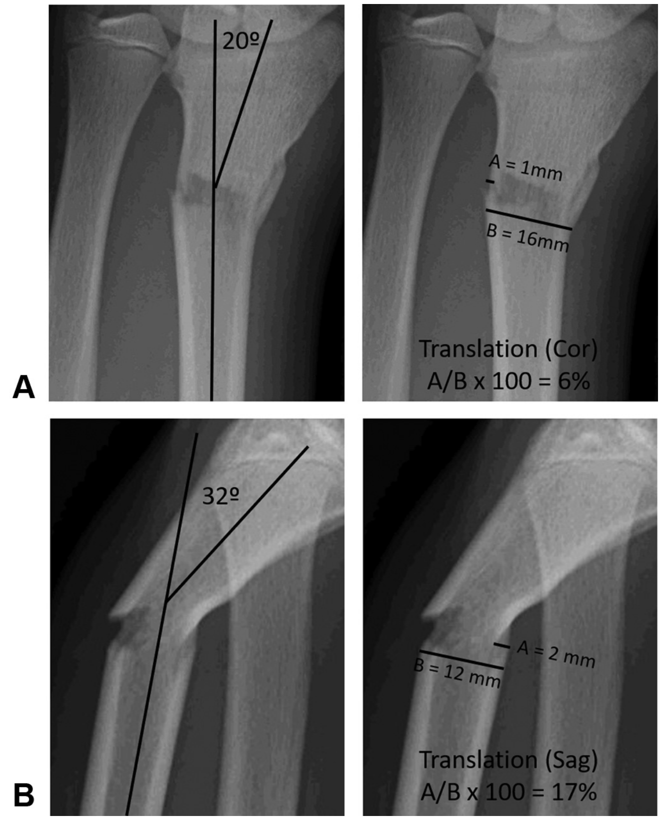

Figure 1. Radiographs of a DRF evaluated in this study, demonstrating sample angulation and translation measurements in the **A** coronal (Cor) and **B** sagittal (Sag) planes on AP and lateral radiographs, respectively.

a bicortical (metaphyseal) fracture. The initial, postreduction, and final fracture angulation and translation were measured for each patient on the AP and lateral radiographs by a single author (B.H.R.) (Fig. 1). Rotational malalignment was not considered because these were DRFs and not diaphyseal fractures. All patients had postreduction imaging within 1 hour of the reduction. The cast index[18] was measured using the earliest available postreduction image. All measurements were made on digital images using measurement tools in Picture Archive and Communication System software (version 4.4.532.11, Philips IntelliSpace PACS Enterprise, Andover, MA). Fracture angulation on both the AP and lateral radiographs was measured as the angle between the 2 lines bisecting each fracture fragment. Fracture translation of both the AP and lateral radiographs, which was recorded as a percentage, was calculated as the width of the nonoverlapping portion of the distal fracture fragment at the level of the fracture. The cast index was measured to represent how well the cast applier achieved interosseous molding to maintain the reduction, and was calculated as the width of the cast at the level of the fracture site in the lateral radiograph divided by the width of the cast at the level of the fracture site in the AP radiograph, as described by Kamat et al.[18] Measurements to determine final outcome were also obtained. For patients who underwent surgical intervention, the most immediate preoperative images were used to assess for LOR; otherwise, images taken at the final follow-up were used.

Outcome measures

Two primary outcome variables for this study were (1) the achievement of acceptable realignment on the initial closed reduction (successful initial reduction), and (2) subsequent loss of an initially successful reduction on follow-up (LOR).

The success of the initial reduction was determined by measuring the fracture angulation and translation on the AP and lateral radiographs on the most immediate postreduction image. Loss of reduction was determined from the follow-up radiograph with the greatest degree of redisplacement. For the purposes of our investigation, criteria defining either successful initial reduction (fracture displacement less than criteria listed) or LOR (fracture displacement greater than criteria listed) were[20]: (1) age less than 10 years: greater than 20° angulation or greater than 50% displacement or surgery; (2) age 10 years or older: greater than 10° angulation or greater than 25% displacement or surgery.

Overall, failed closed reduction was defined as either an unsuccessful initial reduction (UIR) or LOR on follow-up.

Other outcome variables included fluoroscopy time and radiation dose during the closed reduction of the fracture. These data points served as a proxy for reduction difficulty of the fracture.

The decision to perform surgery after failed nonsurgical treatment was based on the discretion of the treating surgeon, which often involved using subjective factors including perceived skeletal maturity, cosmesis, and patient or family preference.

Patient comparison

For analyses related to the 2 primary outcome variables, patients were divided into 2 groups: (1) successful initial reduction versus unsuccessful initial reduction, and (2) LOR versus maintained reduction. Only patients who underwent an initial successful reduction were evaluated for LOR. Patient (age, sex, body mass index (BMI) and fracture characteristics (fracture type, associated ulna fracture, displacement, cast type, and cast index) were compared between groups to identify risk factors for failed closed reduction. In addition, patient and fracture characteristics were evaluated for their association with fluoroscopy time and radiation dose.

Statistical analysis

Standard descriptive summaries (eg, mean and SD for continuous variables and percentage for categorical variables) are used to summarize demographic variables. Comparisons were made between successful versus unsuccessful initial reduction cohorts and LOS versus maintained reduction cohorts using univariate analyses of patient and fracture characteristics via independent-samples *t* tests or Mann-Whitney U tests, depending on the data distribution. Chi-squared or Fisher exact test was performed for categorical data. Multivariate logistic regression analysis was performed for factors that were statistically significant on univariate analysis, to assess for independent predictors for failed closed reduction. Correlations between patient and fracture characteristics and fluoroscopy time or radiation dose were assessed using Spearman rank correlation coefficients. We performed analyses using SPSS Statistics software (version 23, SPSS, Inc, Chicago, IL).

Results

A total of 159 patients (118 boys; mean age, 11 ± 3 years) with displaced DRFs underwent closed reduction and casting. Most (138 of 159; 87%) were placed in long-arm casts, whereas 21 (13%) were placed in short-arm casts. Mean follow-up was 77.1 days (range, 26–326 days). Of the 159 DRFs, 36% were physeal fractures and 64% were bicortical fractures, whereas 75% had an associated distal ulna fracture. Overall, an initial acceptable fracture reduction was achieved in 129 of 159 patients (81.1%), and loss of an acceptable reduction occurred in 28 of 129 patients (21.7%). Thus, the overall rate of failed closed reduction was 58 of 159 patients (36.5%). Eight patients (5%) required surgical reduction (6 closed reduction and percutaneous pinning, and 2 open reduction internal fixation) after a failed closed reduction. No patients underwent remanipulation or wedging other than the 8 patients who underwent surgery.

Reduction difficulty

Initial translation of the fracture in either the sagittal or coronal plane ($P < .001$) and initial angulation in the coronal plane ($P = .007$) were associated with higher time under fluoroscopy based on Spearman correlation coefficients (Table 1). There was also a statistically significant correlation between greater initial translation in either plane ($P < .001$) and initial angulation in the coronal plane ($P = .002$) with radiation dose. Age, BMI, ipsilateral ulna fracture, fracture type, and initial angulation in the sagittal plane were not significantly associated with fluoroscopy time or radiation dose.

Successful initial closed reduction

Patient age, sex, BMI, fracture type, associated ulna fracture, and initial fracture angulation in sagittal and coronal plane did not affect the likelihood of a successful closed reduction (Table 2). Fractures with greater than 60% translation in the sagittal plane were 2.95 times (95% confidence interval [CI], 1.31–6.66; $P = .010$) less likely to undergo a successful initial reduction, whereas those with complete displacement (via translation in the sagittal plane) were 6.18 times (95% CI, 2.54–15.02; $P < .001$) less likely to undergo an initial successful reduction. When there was greater than 45% translation in the coronal plane, there was a 3.55 times (95% CI, 1.3–9.7); $P = .01$) lower likelihood of achieving a successful initial reduction. Patients with UIR required greater fluoroscopy time than did patients who underwent successful initial reduction (26 vs 18 seconds; $P = .002$) (Table 2).

Loss of reduction

There was a statistically significant difference on univariate analysis between median postreduction translation in the sagittal plane ($P = .003$) and cast index ($P = .020$) in patients with subsequent LOR at follow-up versus those who maintained reduction (Table 3). There were no differences between patient age, sex, BMI, fracture type, associated ulna fracture, postreduction translation in the coronal plane, postreduction angulation in either plane, or cast type. In addition, prereduction displacement of the fracture in any plane was not associated with a higher rate of LOR.

Multivariate logistic regression showed that both postreduction translation in the sagittal plane ($P = .015$) and cast index ($P = .033$) were independent predictors for failed closed reduction. Fractures with any residual postreduction translation in the sagittal plane were 4.74 times more likely to lose reduction (95% CI, 1.05–21.3; $P = .03$) than those without translation. Of casts with a CI of 0.8 or less, 9 of 68 (13.2%) went on to LOR, compared with 19 of 61 (31%) with a CI of greater than 0.8 (odds ratio = 2.97; 95% CI, 1.22–7.20; $P = .020$) (Figs. 2, 3).

Discussion

Closed reduction and casting is the mainstay of treatment for displaced pediatric DRFs, although a common and problematic complication remains the high rate of subsequent LOR and redisplacement.[5–7] Thus, there is tremendous value in characterizing the risk factors for LOR, because this would provide guidance for optimizing the nonsurgical treatment of these fractures.

Table 1
Analysis of Baseline Patient and Fracture Characteristics on Fluoroscopy Time and Radiation Dose During Closed Reduction of DRFs*

Variable	Fluoroscopy Time, s	Radiation Dose, mGy
Age	Spearman = −0.073 P = .364	Spearman = 0.006 P = .945
BMI	Spearman = 0.015 P = .854	Spearman = 0.038 P = .639
Ulna fracture (Y/N)	Y: 18 (14–32) N: 18.5 (16.3–26) P = .666	Y: 8.2 (5.2–12.6) N: 8.6 (6.4–13.7) P = .644
Fracture type (physeal [P] or bicortical [B])	P: 18 (13–24.8) B: 19 (14–33) P = .086	P: 7.4 (4.9–11.4) B: 9.3 (5.6–14.1) P = .143
Initial translation: coronal	Spearman = 0.332 P < .001	Spearman = 0.337 P < .001
Initial translation: sagittal	Spearman = 0.315 P < .001	Spearman = 0.312 P < .001
Initial angulation: coronal	Spearman = 0.213 P = .007	Spearman = 0.250 P = .002
Initial angulation: sagittal	Spearman = −0.052 P = .521	Spearman = −0.062 P = .444

* All values are expressed as medians and interquartile ranges.

Table 2
Univariate Analysis of Baseline Patient and Fracture Characteristics and Initial Fracture Displacement in Patients Who Underwent Successful* Versus Unsuccessful Initial Reduction*

Variable	Successful Initial Reduction†	Unsuccessful Initial Reduction	*P* Value
Age	10.7 (8.1–13)	12.2 (10.1–13.5)	.114
BMI	18.5 (16.7–6.3)	19.3 [18.1–21.3)	.249
Fracture type (physeal [P] or bicortical [B])	P: 51 (88%) B: 78 (77%)	P: 7 (12%) B: 23 (23%)	.097
Ulna fracture (Y/N)	Y: 94 (79%) N: 35 (88%)	Y: 25 (21%) N: 5 (12%)	.234
Initial translation (%): coronal	14.0 (8–27)	23.5 (12.3–45.8)	.039
Initial translation (%): sagittal	29 (16–67)	79 (28.3–100)	.003
Initial angulation (degrees): coronal	9 (4–15)	10 (5–17.5)	.331
Initial angulation (degrees): sagittal	24 (15–32)	21.5 (13–30.5)	.601
Fluoroscopy time, s	18 (13–27.6)	26 (17–39)	.002

* All values are expressed as medians (interquartile ranges) or n (%)
† Criteria for successful initial closed reduction were patients aged less than 10 years: less than 20° angulation or less than 50% displacement; patients aged greater than 10 years: less than 10° angulation or less than 25% displacement.

Table 3
Univariate Analysis of Baseline Patient and Fracture Characteristics and Postreduction Fracture Displacement in Patients With LOR Versus Maintained Reduction*

Variable	LOR†	Maintained Reduction	*P* Value
Age	11.7 (10.1–11.7)	10.5 (8–13)	.326
BMI	18.8 (16.4–23.4)	18.3 (16.8–22.5)	.998
Fracture type (physeal [P] or bicortical [B])	P: 9 (18%) B: 18 (23%)	P: 42 (82%) B: 59 (77%)	.437
Ulna fracture (Y/N)	Y: 21 (22%) N: 7 (20%)	Y: 73 (78%) N: 28 (80%)	.774
Initial translation (%): coronal	16 (7.5–32)	14 (8–26)	.630
Initial translation (%): sagittal	43 (17–76)	26 (15–61)	.260
Initial angulation (degrees): coronal	9 (5–15.3)	8 (4–15)	.312
Initial angulation (degrees): sagittal	23.5 (14.5–32)	24 (15–33)	.836
Fluoroscopy time, s	19 (13.8–29.5)	19 (14–33)	.414
Postreduction translation (%): coronal	9.5 (3–14.5)	6 (0–11)	.101
Postreduction translation (%): sagittal	14 (7–20)	9 (0–14)	.003
Postreduction angulation (degrees): coronal	5 (2.8–7.3)	4 (2–6)	.199
Postreduction angulation (degrees): sagittal	6 (3.8–9)	5 (3–8)	.278
Cast index	0.824 (0.781–0.877)	0.773 (0.735–0.846)	.020
Cast type	Short: 4 (33) Long: 20 (27)	Short: 8 (67) Long: 54 (73)	.347

* All values are expressed as medians (interquartile ranges) or n (%).
† Criteria for loss of reduction were patients aged less than 10 years: greater than 20° angulation or greater than 50% displacement or surgery; patients greater than age 10 years: greater than 10° angulation or greater than 25% displacement or surgery.

Furthermore, although several authors advocated for the initial surgical intervention of high-risk DRFs in an effort to circumvent the need for remanipulation, uncertainty remains regarding the precise determinants of high-risk DRFs.

Figure 2. **A** Prereduction, **B** initial reduction, and **C** 2-month postreduction AP and lateral radiographs of a DRF that underwent successful initial reduction with a cast index of less than 0.8 and maintained reduction at 2 months.

The overall rate of UIR or LOR in the current study was 36.5%, with an LOR rate of 21.7%, which is consistent with those reported throughout the literature.[5–7,12,13] Although LOR occurred in approximately 1 in every 5 patients, only 5% required surgical intervention, which is similar to the low rates published elsewhere.[12,13] This may reflect a high tolerance for malunion given the remodeling potential of DRFs in children.

Our study suggests that the most important factors in predicting the outcome of pediatric DRFs after closed reduction are fracture translation and cast index. Specifically, increased initial fracture translation in both the sagittal and coronal plane was associated with a reduced likelihood of achieving a successful initial reduction. With respect to LOR, cast index and residual postreduction translation in the sagittal plane were independently predictive of this outcome.

The degree of initial fracture translation is a common risk factor for LOR described throughout the literature.[5,7,10–16] Several authors showed that fractures with complete initial displacement are at markedly higher risk for reduction loss.[10,13,15,16] In the current study, fractures with complete displacement in the sagittal plate were 6 times less likely to undergo a successful initial reduction, and those with any residual postreduction translation in the sagittal plane were nearly 5 times more likely to lose reduction than those without residual translation. These findings are consistent with several authors who demonstrated the importance of achieving anatomic reduction and avoiding considerable residual postreduction displacement when performing closed reduction.[5,7,11,13]

However, the impact of the specific plane of fracture translation (coronal vs sagittal) has not been well-studied, because most authors have chosen to characterize the DRFs categorically as non-displaced, partially displaced, or fully displaced. Sankar et al[7] separately analyzed DRFs (all with an intact ulna) based on coronal versus sagittal displacement and found that postreduction

Figure 3. **A** Prereduction, **B** initial reduction, and **C** 7-week postreduction AP and lateral radiographs of a DRF that underwent successful initial reduction. The cast index was greater than 0.8 and a follow-up radiograph at 7 weeks revealed LOR.

translation in the coronal plane was independently associated with LOR. Interestingly, our study, which included DRFs with both intact and fractured ipsilateral ulnas, suggests that translation in the sagittal plane, not the coronal plane, may be more important as a predictor for failed closed reduction.

The importance of angulation as a predictor of closed reduction outcome is controversial. Although several authors demonstrated that initial and/or postreduction fracture angulation are not predictors of failed closed reduction,[11–13] other authors showed the opposite.[7,14] Our results demonstrate that although increased initial fracture angulation in the coronal plane was associated with a more difficult reduction, it was not associated with UIR or LOR. There have also been inconsistent findings regarding the difficulty and outcomes of DRF reduction in the setting of either an intact or fractured ipsilateral ulna, because some authors demonstrated a heightened risk of LOR in the presence of a fractured ulna and some demonstrated the opposite.[7,9,10,16,19] Our results suggest that the status of the ulna is not an important factor, because we showed no difference between the rate of successful initial reduction or the rate of LOR in the cohorts with an intact versus fractured ipsilateral ulna.

Our other important risk factor for LOR (cast index) is another controversial topic in the literature. Kamat et al[18] showed that casts with a cast index of greater than 0.81 are particularly prone to redisplacement. Although several studies found similar results and reported increased cast index as a risk factor for redisplacement,[5,13,17,21] other investigators reported that cast index does not appear to be a noteworthy risk factor.[7,12,22] We show that a higher cast index is an independent predictor of LOR, because casts with a cast index of 0.8 of greater were 2.97 times more likely to lose reduction than those with a cast index of less than 0.8. Thus, our data are consistent with the findings of Kamat et al,[18] which advocated a cast index goal of less than 0.8.

Overall, our findings, which highlight the importance of fracture displacement and cast quality, bolster the widely held notion that the ability to achieve an anatomic reduction and apply a well-molded cast are critical factors in the success of nonsurgical management of these fractures. Because these factors are modifiable, it is essential to emphasize the importance of proper reduction maneuvers and casting techniques. Specifically, the treating provider must consider the role of the brachioradialis as a deforming force in the sagittal plane and the need for AP molding to control dorsopalmar reduction, which is ultimately reflected in the measure of cast index.[3,20]

There are several limitations to our study. First, we were able to identify only associations, not causation, between certain risk factors and failed closed reduction given the retrospective study design. Second, our end points were related to DRF outcomes as determined by radiographic measures only, because we did not include data pertaining to functional outcomes of the injured forearm. In addition, although we attempted to achieve measurement reliability by using a single measurer and a consistent method, the possibility remains of measurement variability owing to other factors, including fracture comminution or variability radiographic projection due to patient position. Third, our analysis of variables was not entirely comprehensive, and the possibility that there are additional factors to our outcomes of interest should be considered. For example, we did not collect and analyze data related to time between initial injury and reduction, which may have contributed to the quality of reduction or LOR. In addition, although we believe that fluoroscopy time was a useful and readily available proxy for reduction difficulty, we were unable to determine reliably the number of reduction attempts from the review of the electronic medical record, which would have provided an additional measure of reduction difficulty. Fourth, the low number of patients who underwent surgical intervention (5%) limited our ability to assess risk factors for undergoing surgery, which is certainly an important outcome variable that warrants investigation. Furthermore, given the retrospective study design, the decision to perform surgery was based on the treating surgeon's clinical judgment, and thus there was likely variability in this decision-making. Surgeons often use subjective factors including perceived skeletal maturity, cosmesis, and patient or family preference to make recommendations regarding which patients with radiographic LOR should undergo surgery. Finally, although we looked exclusively at pediatric patients, there was a large range of patient ages and skeletal maturity, each of which may have unique risk factors for failed closed reduction. Each of these should be addressed in future studies. Moreover, systemically reviewing the current literature on failed closed reduction of pediatric DRFs would be useful in developing a comprehensive and accurate prediction model.

Ultimately, our data suggest that postreduction translation in the sagittal plane and cast index are the most important variables in predicting initial closed reduction success and subsequent LOR, whereas the controversial topics of ipsilateral ulna status and fracture angulation did not make appear to make a difference. Postreduction translation in the sagittal plane and cast index are modifiable factors that should be recognized by the treating physician. One strategy for improving surgeon preparation and knowledge in the management of pediatric DRFs is to use simulation training, the incorporation of which was recently shown to reduce the risk for LOR for pediatric DRFs.[22] Nonetheless, the high rate of LOR associated with increased postreduction translation in the sagittal plane may be a specific consideration when determining which patients may benefit from earlier surgical intervention.

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