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Analysis of risk factors for failed closed reduction in pediatric Gartland Type III supracondylar humerus fracture

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Background: Gartland Type III supracondylar humerus fractures (SCHFs) are commonly treated using closed reduction followed by percutaneous pin fixation. However, conversion to open reduction may be necessary if closed reduction fails. This study aimed to identify risk factors associated with failed closed reduction and provide a theoretical basis for clinical decision-making in the treatment of Gartland Type III fractures.

Methods: A retrospective analysis was conducted on children with Gartland Type III SCHF who underwent surgical treatment between April 2017 and June 2018. Based on whether or not the closed reduction was successful, patients were split into the open reduction group and the closed reduction group. Within the closed reduction group, subgroup analysis based on surgery duration was carried out. Data were collected from medical records and X-ray images. Univariate and multivariate regression analyses were utilized to evaluate the relationship between variables and failed closed reduction.

Results: The study included 36 patients in the open reduction group and 135 patients in the closed reduction group. Multivariate analysis revealed that the presence of angle ($P = .024$, OR = 3.199), rotation ($P = .000$, OR = 6.359), skin creases ($P = .013$, OR = 4.077), anterior-posterior displacement ratio ($P = .011$, OR = 4.337), fracture angle in the anteroposterior view ($P = .014$, OR = 0.939), and fracture distal displacement direction ($P = .002$, OR = 5.384) were independent risk factors for failed closed reduction. Subgroup analysis showed that fracture distal displacement direction ($P = .013$), skin folds ($P = .013$), lateral displacement ratio ($P = .016$), and anterior-posterior displacement value ($P = .005$) significantly influenced the duration of closed reduction surgery.

Conclusion: The presence of sharp angle or rotation at the fracture ends, skin folds on the anterior elbow, minor anterior-posterior displacement of the fracture, higher medial inclination of the fracture plane, and distal fracture displacement toward the radial side are independent risk factors for failed closed reduction in pediatric Gartland Type III SCHF.

Level of evidence: Level III; Retrospective Cohort Comparison; Prognosis Study

Keywords: Humeral fractures; risk factors; open fracture reduction; closed fracture reduction; fracture fixation; pediatrics

This retrospective study was approved by the Ethics Review Committee of the Children's Hospital of Nanjing Medical University (study no. 202210181-1). Informed consent was received from the legal guardians of all participants.

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Supracondylar humerus fractures (SCHFs) are the most common elbow joint fractures in children, accounting for approximately 3%–18% of all pediatric fractures.[5,15] Based on the direction of distal displacement, SCHFs can be classified as flexion-type and extension-type, with extension-type fractures comprising 95%–99% of cases.[11,15] Extension-type SCHFs are commonly classified using the Gartland classification system, which categorizes them into Types I to III based on the degree of displacement: Type I represents no displacement, Type II involves displacement with posterior cortical continuity between the fracture fragments, and Type III refers to complete displacement without cortical continuity. The Gartland classification guides clinical treatment selection, with closed reduction and percutaneous pin fixation being the recommended techniques for type III fractures.[2,5,11,15]

Although closed reduction and percutaneous pin fixation are relatively simple procedures with a high success rate, various factors may lead to failed closed reduction. Due to repeated attempts at reduction, open reduction carries a relatively higher risk of iatrogenic injury to the child, prolonged operative time, and increased radiation exposure. Some patients may have severe displacement of fracture fragments or soft tissue entrapment, which makes satisfactory reduction challenging. Additionally, in some cases, poor peripheral blood circulation or even loss of pulse may occur due to vascular or nerve entrapment at the fracture site after reduction. Conversion to open reduction and percutaneous pin fixation should be taken into consideration in these cases.[3,10,11] Furthermore, various factors such as age of the child,[1,6] fracture characteristics,[3,4,12,14] and surgical duration[13] also influence the success rate of closed reduction. As mentioned, numerous studies have separately analyzed the general characteristics of patients, fracture characteristics, and treatment factors that affect the success rate of closed reduction. However, there is a lack of comprehensive analysis of these factors collectively affecting the success rate of closed reduction. Moreover, current studies on fracture characteristics are mostly qualitative, such as the direction of displacement (medial or lateral) or the relative height of the fracture surface. Specific measurements like the exact angle of the fracture plane or the distance of fracture fragment displacement have not been quantitatively analyzed.

Therefore, this study aims to retrospectively analyze various factors including general patient information, fracture characteristics, and treatment factors to investigate the influences on the failure of closed reduction in pediatric Gartland Type III supracondylar humerus fracture. The study aims to explore the risk factors for failed closed reduction in pediatric Gartland Type III SCHF, providing a theoretical basis for clinical treatment decisions.

Methods

This is a retrospective case-control study of the effects of various factors on the failure of closed reduction in pediatric Gartland Type III SCHF.

Patient selection

A retrospective analysis was conducted on children with Gartland type III SCHFs who underwent surgical treatment at our hospital between April 2017 and June 2018. Based on whether or not the closed reduction was successful, patients were split into the open reduction group and the closed reduction group.

The inclusion criteria were as follows: (1) Patients with unilateral fractures who underwent surgical treatment; (2) Initial attempt of closed reduction and internal fixation followed by conversion to open reduction if closed reduction failed; and (3) Complete inpatient medical records and preoperative anteroposterior and lateral X-rays of the elbow joint.

The exclusion criteria were as follows: (1) Congenital upper limb deformities; (2) Coexisting severe cardiovascular, cerebrovascular, or systemic diseases such as tumors; (3) Open fractures, pathologic fractures, or concomitant fractures; (4) Nonemergency fractures (fracture to admission time exceeding 24 hours); and (5) Failure to achieve the criteria for successful reduction (successful reduction defined as postoperative X-rays showing a fracture end distance less than 2 mm, Baumann angle greater than 10° on the anteroposterior view, and the anterior humeral line passing through the middle third of the capitellum on the lateral view).

Analysis of risk factors for failed closed reduction

Medical records of all participants were reviewed to record age, gender, body mass index (BMI), fracture side, presence of nerve injury, presence of elbow ecchymosis, presence of anterior elbow skin creases, emergency management approach (skin traction/cast immobilization), time from fracture to surgery, surgeon's seniority, surgical duration, and surgical approach (closed/open reduction).

Fracture characteristics of all participants were measured using preoperative anteroposterior and lateral X-ray views of the elbow joint: metaphyseal width (o), direction of distal fracture end displacement (medial/lateral), presence of sharp angle at fracture ends, presence of rotation at fracture ends, anteroposterior displacement (a), lateral displacement (b), anteroposterior displacement angle (α), lateral displacement angle (β), fracture angle in the anteroposterior view (θ), and fracture angle in the lateral view (γ) (Figs. 1 and 2). In the anteroposterior view, medial displacement was recorded as positive, while lateral displacement was recorded as negative. Image data collection was performed by 2 trained physicians with over 5 years of specialized experience. WHO growth standards were consulted to record the average BMI for each age.

To enhance comparability due to age differences, some of the measured values were processed to obtain the following parameters: BMI difference ratio, absolute value of the fracture angle in the anteroposterior view ($|\theta|$), absolute value

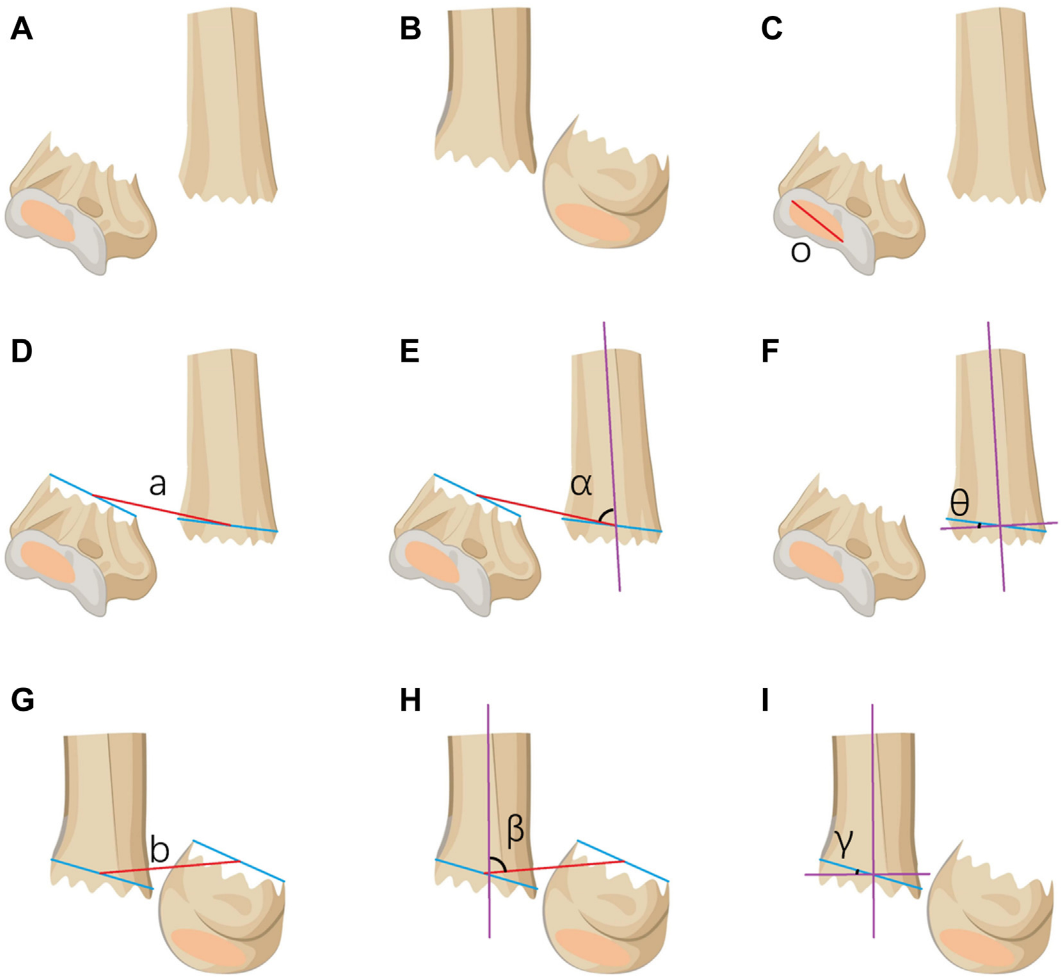

Figure 1 Schematic diagram of quantitative fracture characteristics on X-ray images. **(A)** Elbow joint anteroposterior X-ray. **(B)** Elbow joint lateral X-ray. **(C)** Measurement of epiphyseal width (o) on the anteroposterior view of the elbow joint: the maximum distance between the ends of the epiphysis. **(D)** Measurement of displacement (a) on the anteroposterior view: the length of the line (*red*) connecting the midpoints of the 2 fracture lines (*blue*). **(E)** Measurement of displacement angle (α) on the anteroposterior view: the angle between the humeral shaft axis (*purple*) and the line of fracture displacement (*red*). **(F)** Measurement of fracture angle (θ) on the anteroposterior view: the angle between the vertical line of humeral shaft axis (*purple*) and the proximal fracture line (*blue*). **(G)** Measurement of displacement (b) on the lateral view: the length of the line (*red*) connecting the midpoints of the 2 fracture lines (*blue*). **(H)** Measurement of displacement angle (β) on the lateral view: the angle between the humeral shaft axis (*purple*) and the line of fracture displacement (*red*). **(I)** Measurement of fracture angle (γ) on the lateral view: the angle between the vertical line of humeral shaft axis (*purple*) and the proximal fracture line (*blue*).

of the fracture angle in the lateral view(|γ|), lateral displacement value (x), absolute value of lateral displacement (|x|), lateral displacement ratio (l), absolute value of lateral displacement ratio (|l|), vertical displacement value (y), vertical displacement ratio (m), anterior-posterior displacement value (z), and anterior-posterior displacement ratio (n) (Figs. 3 and 4).

BMI difference ratio = (BMI of the participant - Average BMI of the same age)/Average BMI of the same age

$x = a * \sin(\alpha)$

$l = x/o$

$y = (a * \cos(\alpha) + b * \cos(\beta))/2$

$m = y/o$

$z = b * \sin(\beta)$

$n = z/o.$

Analysis of surgical duration in the closed reduction group

Analyze the factors affecting surgical duration based on the collected data of patients with successful closed reduction.

Statistical analysis

Quantitative variables were expressed as mean ± standard deviation, and normal distribution was assessed using the Kolmogorov–Smirnov test. Qualitative variables were presented as frequencies.

Firstly, univariate analysis was performed to evaluate the correlation between each factor and the dependent variable.

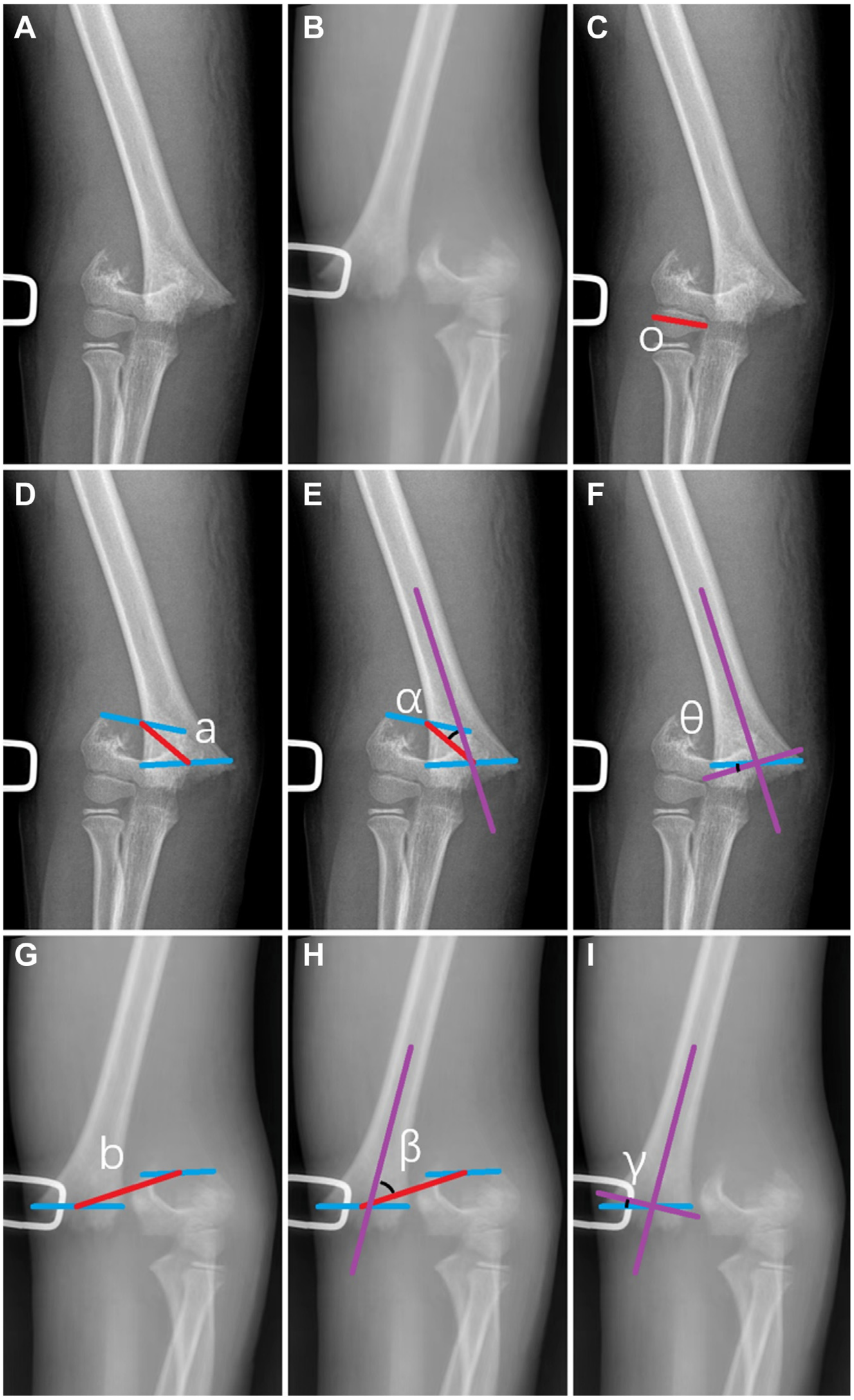

Figure 2 X-ray images of a male patient (age, 9.45 years) with Gartland III supracondylar humerus fracture. **(A-I)** Same as Figure 1.

Pearson correlation analysis (for variables with normal distribution) or Spearman correlation analysis (for variables with non-normal distribution) was used for assessing the correlation between two quantitative variables. Chi-square test or Fisher's exact test was employed for analyzing the association between two qualitative variables. Independent samples t-test (for variables with normal distribution) or Mann–Whitney test (for variables with non-normal distribution) was used to evaluate the relationship between quantitative and qualitative variables. When making multiple comparisons, make a Benjamini–Hochberg correction for multiple P values, with the critical value for a false discovery rate of 0.250.

Multivariate logistic regression analysis was conducted for qualitative dependent variables. Variables with a significance level of $P < .100$ were subsequently integrated into a multivariate logistic regression model, and a stepwise backward elimination

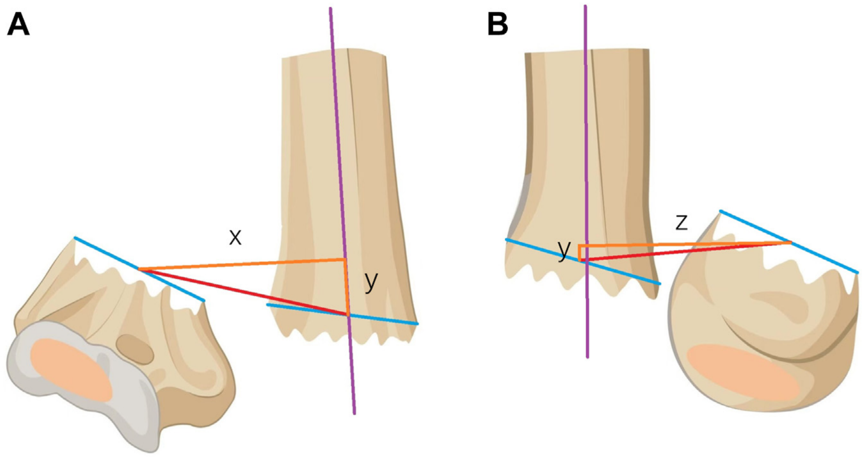

Figure 3 Schematic diagram of processed values on X-ray images. **(A)** The first *orange line* passes through the midpoint of the proximal *fracture line* and is parallel to the humeral shaft axis (*purple*). The second *orange line* passes through the midpoint of the distal *fracture line* and is perpendicular to the humeral shaft axis (*purple*). Two *orange lines* intersect and form 2 segments, representing the x and y, respectively. **(B)** The first *orange line* passes through the midpoint of the proximal *fracture line* and is parallel to the humeral shaft axis (*purple*). The second *orange line* passes through the midpoint of the distal *fracture line* and is perpendicular to the humeral shaft axis (*purple*). Two *orange lines* intersect and form 2 segments, representing the z and y, respectively.

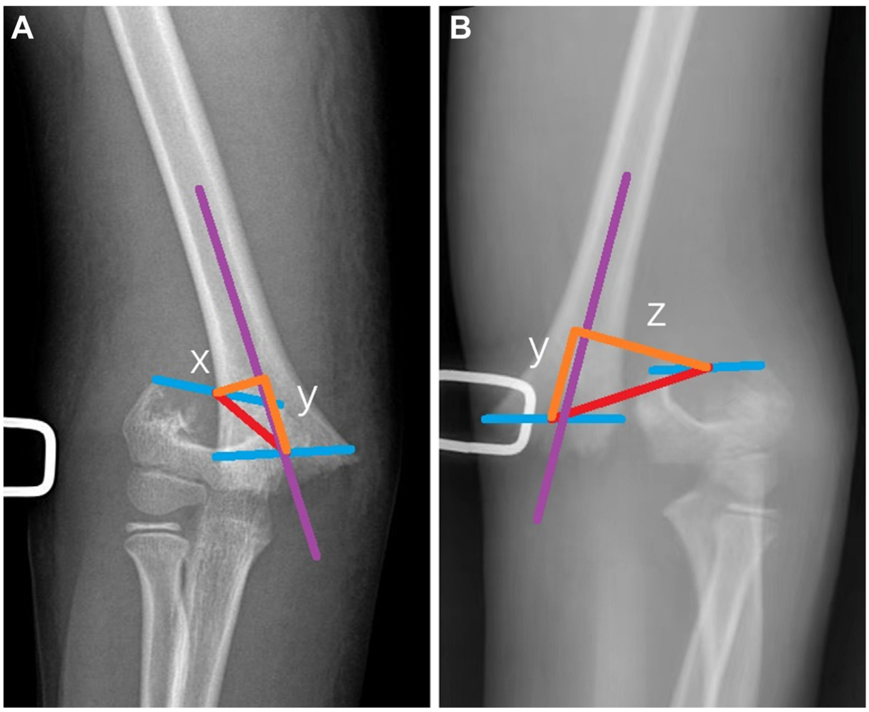

Figure 4 Processed values on X-ray images of a male patient (age, 9.45 years) with Gartland III supracondylar humerus fracture. **(A and B)** Same as Figure 3.

method was employed. The association between independent and dependent variables was expressed as odds ratios (ORs). Multiple linear regression analysis was performed for quantitative dependent variables.

All statistical analyses were conducted using the SPSS 24.0 software package (IBM, Armonk, NY, USA) with two-tailed tests. Statistical significance was defined as $P < .050$.

Results

Analysis of risk factors for failed closed reduction

A total of 171 pediatric patients were included in the study. The open reduction group consisted of 29 male

Table I Univariate analysis of the open and closed groups

	Open group	Closed group	χ^2/t	*P* value
Age (yr)	6.39 ± 1.73	5.40 ± 2.40	2.813	.006*
Gender				
Male	29	78	6.296	.012*
Female	7	57		
BMI difference ratio (%)	6.13 ± 18.10	6.21 ± 14.53	0.029	.977
Fracture side				
Left	15	81	3.880	.049*
Right	21	54		
Nerve injury				
Yes	12	33	1.158	.282
No	24	102		
Elbow ecchymosis				
Yes	29	87	3.381	.066
No	7	48		
Anterior elbow skin creases				
Yes	11	16	7.478	.006
No	25	119		
Emergency management				
Skin traction	32	118	0.058	.810
Cast immobilization	4	17		
Direction of distal fracture displacement				
Medial	19	94	3.601	.058
Lateral	17	41		
Sharp angle at fracture ends				
Yes	15	29	6.060	.014*
No	21	106		
Rotation at fracture ends				
Yes	18	23	16.942	.000*
No	18	112		
Lateral displacement value (x) (mm)	1 ± 9	0 ± 1	0.664	.510
Lateral displacement ratio (l)	0.12 ± 0.71	4.58 ± 1.23	0.714	.476
Absolute value of lateral displacement (|x|) (mm)	8 ± 5	6 ± 5	2.054	.042*
Absolute value of lateral displacement ratio (|l|)	0.57 ± 0.43	0.52 ± 0.44	0.616	.539
Vertical displacement value (yr) (mm)	12 ± 7	11 ± 6	0.680	.497
Vertical displacement ratio (m)	1 ± 1	1 ± 1	0.822	.412
Anterior-posterior displacement value (z) (mm)	9 ± 6	10 ± 6	0.984	.327
Anterior-posterior displacement ratio (n)	0.66 ± 0.46	0.85 ± 0.48	2.161	.032*
Fracture angle in the anteroposterior view (θ) (°)	−3±10	−6±10	1.682	.094
Absolute value of the fracture angle in the anteroposterior view (|θ|) (°)	9 ± 5	10 ± 7	0.361	.719
Fracture angle in the lateral view (γ) (°)	−7 ± 13	−5 ± 12	0.720	.472
Absolute value of the fracture angle in the lateral view (|γ|) (°)	12 ± 9	10 ± 8	1.254	.212
Time from fracture to surgery (d)	3.50 ± 1.68	3.06 ± 1.69	1.391	.166
Surgeon's seniority (yr)	14.44 ± 3.15	14.21 ± 5.05	0.348	.729

BMI, body mass index.
* $P < .050$.

and 7 female patients, with a mean age of 6.39 ± 1.73 years (range: 2.18 to 10.55 years). The closed reduction group comprised 78 male and 57 female patients, with a mean age of 5.40 ± 2.40 years (range: 1.07–11.58 years).

Univariate analysis showed significant differences between the open reduction and closed reduction groups in terms of age ($P = .006$), gender ($P = .012$), fracture side ($P = .049$), presence of sharp angle at fracture ends ($P = .014$), presence of rotational deformity at fracture ends ($P = .000$), presence of anterior elbow skin creases ($P = .006$), absolute value of lateral displacement (|x|) ($P = .042$), anterior-posterior displacement ratio (n) ($P = .032$), fracture angle in the anteroposterior view (θ) ($P = .094$), direction of distal fracture end displacement ($P = .058$), and presence of elbow ecchymosis

Table II Benjamini–Hochberg correction for univariate analysis of the open and closed groups

	P value	Rank	(i/m) Q
Rotation at fracture ends	.000	1	0.010
Age (yr)	.006	2	0.020
Anterior elbow skin creases	.006	3	0.030
Gender	.012	4	0.040
Sharp angle at fracture ends	.014	5	0.050
Anterior-posterior displacement ratio (n)	.032	6	0.060
Absolute value of lateral displacement (|x|) (mm)	.042	7	0.070
Fracture side	.049	8	0.080
Direction of distal fracture displacement	.058	9	0.090
Elbow ecchymosis	.066	10	0.100
Fracture angle in the anteroposterior view (θ) (°)	.094	11	0.110
Time from fracture to surgery (d)	.166	12	0.120
Absolute value of the fracture angle in the lateral view (|γ|) (°)	.212	13	0.130
Nerve injury	.282	14	0.140
Anterior-posterior displacement value (z) (mm)	.327	15	0.150
Vertical displacement ratio (m)	.412	16	0.160
Fracture angle in the lateral view (γ) (°)	.472	17	0.170
Lateral displacement ratio (l)	.476	18	0.180
Vertical displacement value (yr) (mm)	.497	19	0.190
Lateral displacement value (x) (mm)	.510	20	0.200
Absolute value of lateral displacement ratio (|l|)	.539	21	0.210
Absolute value of the fracture angle in the anteroposterior view (|θ|) (°)	.719	22	0.220
Surgeon's seniority (yr)	.729	23	0.230
Emergency management	.810	24	0.240
BMI difference ratio (%)	.977	25	0.250

BMI, body mass index; *i*, rank, *m*, the total number; *Q*, 0.250.

(P = .066) (Tables I and II). In the multivariate analysis, the significant independent influencing factors for failed closed reduction were presence of sharp angle at fracture ends (P = .024, OR = 3.199), presence of rotation at fracture ends (P = .000, OR = 6.359), presence of anterior elbow skin creases (P = .013, OR = 4.077), anterior-posterior displacement ratio (n) (P = .011, OR = 4.337), θ (P = .014, OR = 0.939), and direction of distal fracture end displacement (P = .002, OR = 5.384) (Table III). The logistic regression model was statistically significant (χ^2 = 45.465, P = .000), correctly classifying 86.5% of the study subjects.

Analysis of surgical duration in the closed reduction group

Univariate analysis showed that direction of distal fracture end displacement (P = .013), presence of anterior elbow skin creases (P = .013), lateral displacement ratio (l) (P = .016), and anterior-posterior displacement value (z) (P = .005) had a significant effect on the surgical duration. The BMI difference ratio (P = .094), lateral displacement value (x) (P = .054), and emergency management approach (P = .091) were found to influence the surgical duration (Tables IV and V). Multiple linear regression analysis was performed, and the regression model was statistically significant (χ^2 = 3.584, P = .003). However, none of the included independent variables in the model had a statistically significant impact on the surgical duration (Table VI).

Discussion

Pediatric SCHFs are highly common, accounting for approximately 3%–18% of all pediatric fractures.[5,15] Currently, the recommended clinical treatment for Gartland Type III fractures is closed reduction and percutaneous pin fixation. However, various factors may lead to failed closed reduction, necessitating conversion to open reduction. This study aimed to analyze and explore the risk factors for failed closed reduction in pediatric SCHFs, providing a theoretical basis for clinical treatment decisions.

SCHFs are most prevalent in children aged 5 to 7 years, with the incidence gradually decreasing as age increases.[5,6,12] Consistent with these data, the mean ages of the open reduction group and the closed reduction group in this study were 6.39 ± 1.73 years and 5.40 ± 2.40 years, respectively. It was discovered that older children were more likely to experience closed reduction failure (P = .006). Bekmez et al[1] suggested that age does not affect the success rate of closed reduction, but their study included Gartland II fractures and T-shaped distal humerus fractures. Additionally, they discovered that the distribution of fracture types changes with increasing age and skeletal maturity, potentially masking the impact of age on the success rate of closed reduction in Gartland Type III SCHFs. Furthermore, Li et al[6] also conducted research that aligns with our findings, reporting that children aged 10 and above with Gartland Type III SCHFs often underwent open reduction.

In our study, a higher proportion of male patients was observed, potentially attributed to male children's greater participation in various sports activities. It's interesting to note that the success rate of closed reduction was lower in male patients (P = .012). However, the conclusions drawn by LiBrizzi et al[8] contradicted this observation. They found no gender-based differences in fracture occurrence. Future

Table III Multiple logical regression analysis of the open and closed groups

	Regression coefficient	Standard error	Wald	Odds ratio	*P* value
Anterior elbow skin creases	1.405	0.564	6.216	4.077	.013
Direction of distal fracture displacement	1.683	0.546	9.491	5.384	.002
Sharp angle at fracture ends	1.163	0.514	5.119	3.199	.024
Rotation at fracture ends	1.850	0.503	13.504	6.359	.000
Anterior-posterior displacement ratio (n)	1.467	0.573	6.546	4.337	.011
Fracture angle in the anteroposterior view (θ)	−0.063	0.026	6.059	0.939	.014
Constant	−4.235	1.034	16.792	0.014	.000

research into this discrepancy is necessary. Regarding the influence of age and gender on the success rate of closed reduction, we speculate that it may be related to greater muscle strength in older or male children, which could increase the difficulty of closed reduction due to the need for countertraction during the process.

In the subgroup analysis of this study, an increase in the BMI difference ratio was associated with prolonged surgical duration in the closed reduction group, which partially supports our previous speculation. However, the effect of BMI on the failure of closed reduction is still a matter of debate. Li et al[7] conducted a study on the impact of obesity on surgical treatment of pediatric SCHFs and found that in children under 8 years of age, the rate of open reduction did not increase in obese patients compared to normal-weight patients, while in obese children aged 8–12 years, the rate of open reduction was four times higher than that of normal-weight children.

Another noteworthy finding in our study was that fractures on the right side had a lower success rate of closed reduction ($P = .049$). We hypothesize that this may be since the techniques required for fractures on different sides are mirror images of each other, but surgeons typically have a dominant hand for performing the procedure. When reducing a fracture on the right side, the surgeon may not be able to exert the same amount of force as when reducing a fracture on the left side, which could affect the success rate of fracture reduction. Nevertheless, additional focused research is still needed to support this argument.

The characteristics of SCHFs are believed to have a significant impact on the success rate of closed reduction. In our study, we innovatively conducted a three-dimensional evaluation of fracture characteristics through processing two-dimensional image data. This made it possible to conduct a detailed quantitative analysis of fracture displacement distance and angle, which is unique among existing studies. We found that as the absolute value of lateral displacement ($|x|$) increased, the success rate of closed reduction decreased ($P = .042$). This is easily understandable as an increase in lateral displacement implies a greater severity of the fracture. Similarly, the increase in lateral displacement ratio (l) and lateral displacement value (x) were associated with prolonged surgical duration ($P = .016$ and $P = .054$, respectively). However, a decrease in anterior-posterior displacement ratio (n) ($P = .011$, OR = 4.337) became an independent risk factor for failed closed reduction, and a decrease in anterior-posterior displacement value (z) ($P = .005$) led to an increased duration of closed surgery, seemingly contradicting our earlier speculations. This could be explained by the fact that shorter anterior-posterior displacement often indicates impaction of the distal and proximal bone segments, requiring greater traction distance during reduction.

We also observed that a higher fracture angle in the anteroposterior view (θ) was associated with a lower success rate of closed reduction ($P = .014$, OR = 0.939). In a study by Segal et al,[12] it was found that children with greater fracture surface inclination had a lower success rate of closed reduction. However, our study did not come to the same conclusion. Heffernan et al[4] conducted an interesting study in which they proposed a novel type of fracture called "reverse oblique," where the fracture ends in the lateral view were relatively higher in the anterior aspect compared to the posterior aspect, opposite to the usual anteriorly lower than posterior configuration. They discovered that traditional closed reduction methods were ineffective for this type of fracture and suggested special techniques for closed reduction. Our study also revealed that the presence of anterior elbow skin creases ($P = .013$, OR = 4.077) indicated an increased failure rate of closed reduction. This phenomenon suggests that the fracture ends have penetrated the muscle tissue in front of the elbow joint and reached the subcutaneous layer, significantly increasing the difficulty of reduction. Attempting closed reduction in such cases requires "milking" technique to extract the fracture ends from the muscle tissue, but this method is challenging and has a high failure rate. In our study, distal fracture end displacement toward the lateral side ($P = .002$, OR = 5.384), presence of sharp angle at fracture ends ($P = .024$, OR = 3.199), and presence of rotation at fracture ends ($P = .000$, OR = 6.359) were all independent risk factors for failed closed reduction. These findings align with our clinical experience, and we hypothesize that these 3 factors are related to the anatomy of the distal humerus. When the fracture ends exhibit such characteristics, they

Table IV Univariate analysis of surgical duration in the closed reduction group

	Surgical duration (min)	Correlation coefficient/t	*P* value
Age (yr)	-	0.137	.112
Gender			
Male	27.69 ± 11.42	0.116	.908
Female	27.46 ± 12.11		
BMI difference ratio (%)	-	0.145	.094
Fracture side			
Left	27.65 ± 11.70	0.075	.940
Right	27.50 ± 11.73		
Nerve injury			
Yes	29.39 ± 12.67	1.020	.309
No	27.01 ± 11.33		
Elbow ecchymosis			
Yes	28.05 ± 11.82	0.606	.545
No	26.77 ± 11.46		
Anterior elbow skin creases			
Yes	34.38 ± 14.01	2.526	.013*
No	26.68 ± 11.07		
Emergency management			
Skin traction	26.95 ± 11.40	1.700	.091
Cast immobilization	32.06 ± 12.88		
Direction of distal fracture displacement			
Medial	25.96 ± 10.83	2.514	.013*
Lateral	31.34 ± 12.75		
Sharp angle at fracture ends			
Yes	26.21 ± 11.55	0.720	.473
No	27.97 ± 11.73		
Rotation at fracture ends			
Yes	26.96 ± 13.03	0.286	.775
No	27.72 ± 11.43		
Lateral displacement value (x) (mm)	-	0.116	.054
Lateral displacement ratio (l)	-	0.208	.016*
Absolute value of lateral displacement (|x|) (mm)	-	0.044	.616
Absolute value of lateral displacement ratio (|l|)	-	0.029	.738
Vertical displacement value (yr) (mm)	-	0.014	.868
Vertical displacement ratio (m)	-	0.078	.371
Anterior-posterior displacement value (z) (mm)	-	0.240	.005*
Anterior-posterior displacement ratio (n)	-	0.131	.131
Fracture angle in the anteroposterior view (θ) (°)	-	0.128	.138
Absolute value of the fracture angle in the anteroposterior view (|θ|) (°)	-	0.083	.341
Fracture angle in the lateral view (γ) (°)	-	0.079	.364
Absolute value of the fracture angle in the lateral view (|γ|) (°)	-	0.086	.322
Time from fracture to surgery (d)	-	0.027	.756
Surgeon's seniority (yr)	-	0.072	.405

BMI, body mass index.
* $P < .050$.

are more prone to become embedded in the surrounding soft tissues, making reduction challenging.

Our study offers a novel methodology by performing detailed quantitative and qualitative analyses of fracture characteristics. The data were manually collected, and while efforts were made to maximize the sample size, errors still exist. Negrillo–Cárdenas et al[9] proposed a computer algorithm for automated detection of humeral landmarks and analysis of supracondylar humerus fracture reduction. The growing use of artificial intelligence in orthopedics, further integration of digital medicine, and AI technologies can provide valuable insights and improve the accuracy of analyses.

This study has several limitations. This is a single center retrospective study with selection bias, thus it is necessary to conduct a multicenter study and increase the sample size in the future. Furthermore, the data on fracture characteristics were obtained from preoperative X-ray images, which

Table V Benjamini–Hochberg correction for univariate analysis of surgical duration in the closed reduction group

	P value	Rank	(i/m) Q
Anterior-posterior displacement value (z) (mm)	.005	1	0.010
Anterior elbow skin creases	.013	2	0.020
Direction of distal fracture displacement	.013	3	0.030
Lateral displacement ratio (l)	.016	4	0.040
Lateral displacement value (x) (mm)	.054	5	0.050
Emergency management	.091	6	0.060
BMI difference ratio (%)	.094	7	0.070
Age (yr)	.112	8	0.080
Anterior-posterior displacement ratio (n)	.131	9	0.090
Fracture angle in the anteroposterior view (θ) (°)	.138	10	0.100
Nerve injury	.309	11	0.110
Absolute value of the fracture angle in the lateral view (|γ|) (°)	.322	12	0.120
Absolute value of the fracture angle in the anteroposterior view (|θ|) (°)	.341	13	0.130
Fracture angle in the lateral view (γ) (°)	.364	14	0.140
Vertical displacement ratio (m)	.371	15	0.150
Surgeon's seniority (yr)	.405	16	0.160
Sharp angle at fracture ends	.473	17	0.170
Elbow ecchymosis	.545	18	0.180
Absolute value of lateral displacement (|x|) (mm)	.616	19	0.190
Absolute value of lateral displacement ratio (|l|)	.738	20	0.200
Time from fracture to surgery (d)	.756	21	0.210
Rotation at fracture ends	.775	22	0.220
Vertical displacement value (yr) (mm)	.868	23	0.230
Gender	.908	24	0.240
Fracture side	.940	25	0.250

BMI, body mass index; *i*, rank, *m*, the total number; *Q*, 0.250.

Table VI Multiple linear analysis of surgical duration in the closed group

	Regression coefficient	β	*P* value
BMI difference ratio	0.044	0.061	.471
Anterior elbow skin creases	6.363	0.177	.052
Emergency management	5.656	0.161	.057
Direction of distal fracture displacement	3.706	0.147	.230
Lateral displacement ratio (l)	−0.481	−0.023	.851
Anterior-posterior displacement value (z)	0.328	0.170	.062
Constant	11.972	-	.041

BMI, body mass index.

might have varying imaging angles and errors, particularly in younger patients. Consideration of patients with preoperative CT images could alleviate this issue. Moreover, the determination of the presence of sharp angles and rotation at fracture ends relied on subjective judgments, lacking objective quantification. Previous study publications have not given us a method for objective quantitative measurement. We will keep working to the best of our ability to develop an objective quantitative measurement approach for these 2 items. Lastly, the number of attempted closed reductions during surgery was not recorded, warranting further investigation for recommendations on the optimal number of attempts.

Conclusion

Presence of sharp angle or rotation at the fracture ends, skin folds on the anterior elbow, minor anterior-posterior displacement of the fracture, higher medial inclination of the fracture plane, and distal fracture displacement toward the radial side are independent risk factors for failed closed reduction in pediatric Gartland Type III SCHF. For patients with these characteristics, it is advisable to avoid blind and repetitive attempts at closed reduction during surgery.

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