Development and Validation of a Predictive Model for the Prognosis of Complications of Supracondylar Fractures of The Humerus in Children

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Abstract: Objective: Informing patient consultations and healthcare choices, clinical predictive models can offer patients tailored projections of the outcome. The most frequent elbow fractures in children are supracondylar humerus fractures, and clinical prediction models were still largely underutilized in these cases. By developing and verifying a prediction model to lower the risk of postoperative problems in children with supracondylar humerus fractures, this research sought to evaluate independent risk variables connected with the incidence of complications of supracondylar humerus fractures in children. Methods: We retrospectively studied 411 children with supracondylar humerus fractures treated surgically at our hospital from 2015 to 2019, and explored the independent risk factors affecting the prognosis of supracondylar humerus fractures in children in the study group using univariate and multifactorial Cox regression analysis, respectively. In addition, a prediction model based on the independent factors was constructed, a nomogram was made and data from the two cohorts were used to verify the feasibility and reliability of the model and visualize the data. Results: Height, older than eight years, weight, nerve damage, fracture type and with joystick technology of the child as independent risk factors influenced the prognosis of pediatric supracondylar humerus fractures in the modeling constructed by the training cohort, respectively. The results of the validation cohort were further screened for older than eight years, nerve injury and fracture type as independent prognostic factors. Conclusions: We were able to construct a predictive model based on a large genuine data sample, and clinical characteristics in this model could be used as independent predictors for reducing the occurrence of postoperative complications in supracondylar fractures. Combining basic vital signs and clinical risk factors into a simple and clear nomogram was more likely to result in the best treatment plan.

Keywords: Supracondylar Fracture of the Humerus In Children; Predictive Model; Independent Factors

1. Introduction

Supracondylar humeral fractures (SCHF) account for 18% of fracture types in children and reach 60% of elbow fractures in children. They usually occur in children aged 5 to 10 years[1,2]. According to epidemiological statistics, the majority of supracondylar fractures of the humerus are extension fractures, which account for about 97%-99%[3]. The rest are flexion fractures. In addition, supracondylar fractures of the humerus are also classified into three types in the Gartland classification according to the degree of displacement of the fracture. Type I and IIa fractures are stable fractures and can be fixed in a cast. Type II b and III fractures usually require surgical treatment[2,4].

Closed reduction and percutaneous pinning(CRPP) is used as the surgical method of choice for SCHF in children[4,5].

Short operative time, minor surgical side injuries, and low risk of surgical site infection are the advantages of this procedure. However, the occurrence of postoperative complications causes the time for fracture healing to be prolonged, making the postoperative recovery of the fracture different from the ideal situation. For this reason, this review analyzed the risk factors for postoperative fracture complications in children with SCHF admitted to the Affiliated Hospital of Chengde Medical College. The prediction model for multiple risk factors for postoperative supracondylar fractures of the humerus was constructed as a predictive model of independent factors for the prognosis of fractures in children with supracondylar fractures of the humerus, to explore the indicators affecting the prognosis of supracondylar fractures in children.

2. Objects and methods

2.1 Subjects

This study was a retrospective study analysis. A total of 411 children with supracondylar fractures of the humerus were included in the study, of whom 168 were male. All children underwent surgery at the Affiliated Hospital of Chengde Medical College from September 2015 to June 2019. Inclusion criteria: 1: those with complete medical history; 2: preoperative diagnosis of unstable supracondylar humerus fracture; 3: not accompanied by multiple fractures. Exclusion criteria: 1: the patient had a history of multiple fractures; 2: those with preoperative co-infection; 3: patients with chronic diseases. This study was approved by the Ethics Committee of the Affiliated Hospital of Chengde Medical College.

2.2 Study indicators

All children's general information were collected, and item-by-item univariate analysis and COX regression analysis were performed on this basis. The clinical information involved contained height, weight, gender, side, BMI, open fracture, older than eight years, time from injury to surgery, type of fracture, number of Kirschner, nerve damage, surgical method, and operation time.

2.3 Statistical analysis

SPSS 20.0 software was applied to statistically analyze the test data. Height, weight, age, BMI, and continuous variables such as time are converted into categorical variables. The single-factor analysis was carried out by binary logistic regression. The indexes with p-value less than 0.05 were summarized and analyzed by multivariate logistic regression analysis. The risk factors for the final prediction model were screened out. The prediction model was established using State software, and the independent risk factors that could influence the prognosis of fractures were screened using COX regression analysis. The consistency index (C-index) was calculated, with less than 0.05 being considered as a model without predictive ability, between 0.05 and 0.07 as a model with low discrimination, 0.07-0.09 as a model with moderate discrimination, and greater than 0.09 as a model with high discrimination, with C-index=1.0 indicating complete agreement between the model and the results. The effectiveness of the clinical prediction model was assessed using the Receiver operating characteristic curve (ROC) and the Area under the curve (AUC), and a p-value of less than 0.05 was considered a statistically significant difference.

3. Results

3.1 Comparison of basic information of collected data, see Table 1 for details.

Table 1 Comparison of basic information of collected data

A *p*-value＜0.05 was statistically significant.

	train		P	verification		*P*
	Out=0	Out=1		Out=0	Out=1	
n	192	95		88	36	
Height(cm)	110(96,120)	128(113,140)	＜0.001	110(103.5,125)	140(120.5,145)	0.642
Weight(kg)	20(15,25)	26(20,37)	＜0.001	20(16,28.7)	34(23,40.5)	0.324
Sex(male)	109(56.8%)	59(62.1%)	0.45	48(55%)	26(72%)	0.074
Left	103(53.6%)	47(49.5%)	0.53	45(51%)	25(69%)	0.074
BMI	16.53(14.87, 19.91)	15.98(14.86, 19.20)	0.51	16.56(15.10, 18.99)	17.98(14.79, 22.04)	0.280
Duration of injury(h)	4(3.9)	4(3,7)	0.74	4(3,10)	6(4.11)	0.200
Older than 8 years	5(3.6)	8(5,10)	＜0.001	6(4,7)	9(8.10.5)	＜0.001
Open	0(0.0%)	2(2.1%)	0.11	0(0.0)	0(0.0)	1
Type(III)	47(24.5%)	56(58.9%)	＜0.001	27(31%)	17(47%)	0.026
Nerve damage	21(10.9%)	22(23.2%)	0.008	8(9%)	6(17%)	0.028
Kirschner	190(99.0%)	93(96.8%)	0.34	85(97%)	36(100%)	0.560
Prying	21(10.9%)	22(23.2%)	0.008	13(15%)	5(14%)	1
Kirschner Less than2	29(15.1%)	10(10.5%)	0.36	33(38%)	8(22%)	0.140
Inone	4(2.1%)	5(5.3%)	0.16	1(1%)	0(0%)	1
external fixator	0(0.0%)	2(2.1%)	0.11	6(7%)	1(3%)	0.670
Surgery time(time)	51(34.5,95)	49(40,77)	0.61	48(28,72)	61.5(45.5,90.5)	0.042

As shown in Figure 1, the performance in the nomogram conventional scoring system achieved the ideal situation regardless of the threshold, both in the training cohort and in the validation verification cohort, which ensured that the maximum clinical benefit was obtained. Finally, decision curve analysis (DCA) demonstrated that our proposed nomogram mode can be used to make valuable and profitable decisions. These results were also validated in the validation cohort. (Figure 2).

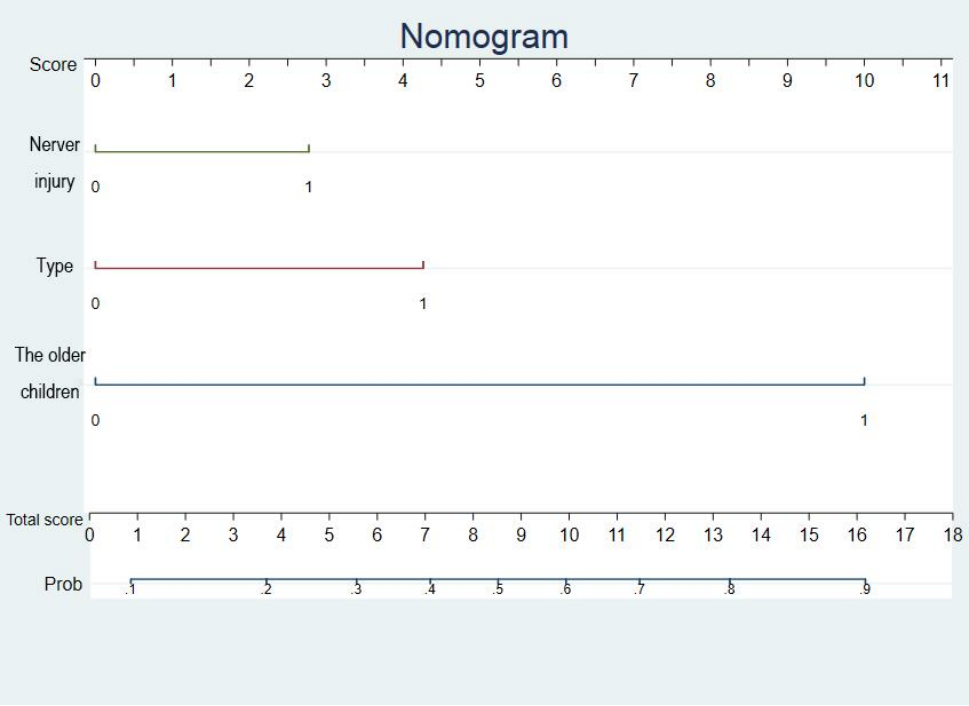

Figure 1 nomogram.

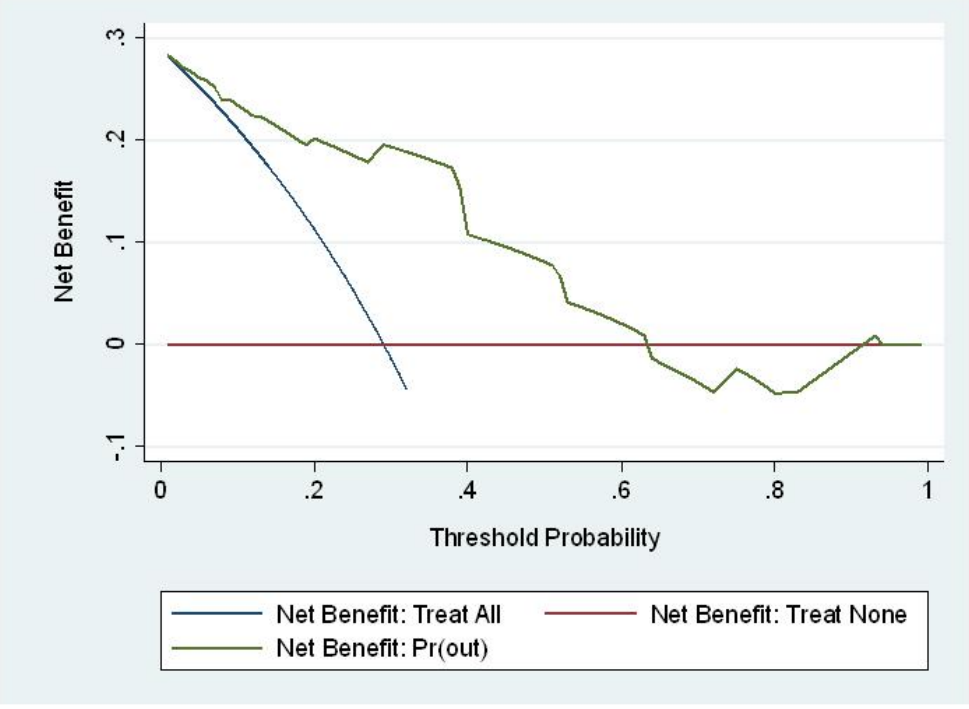

Figure 2 the decision curve analysis.

The established nomograms yielded C indices of 0.86 (95 % CI, 0. 81-0. 90) and 0. 86 (95% CI, 0. 79-0. 93) in the training and validation verification cohorts, respectively, using a study cohort of 411 (male, 242; female, 169) patients with supracondylar humerus fractures from the same dataset. Figures 3 and 4 are examples of this. Accordingly, the calibration curves showed that the probability of occurrence of postoperative complications predicted using the nomogram was consistent with the actual occurrence values (Figure 5).

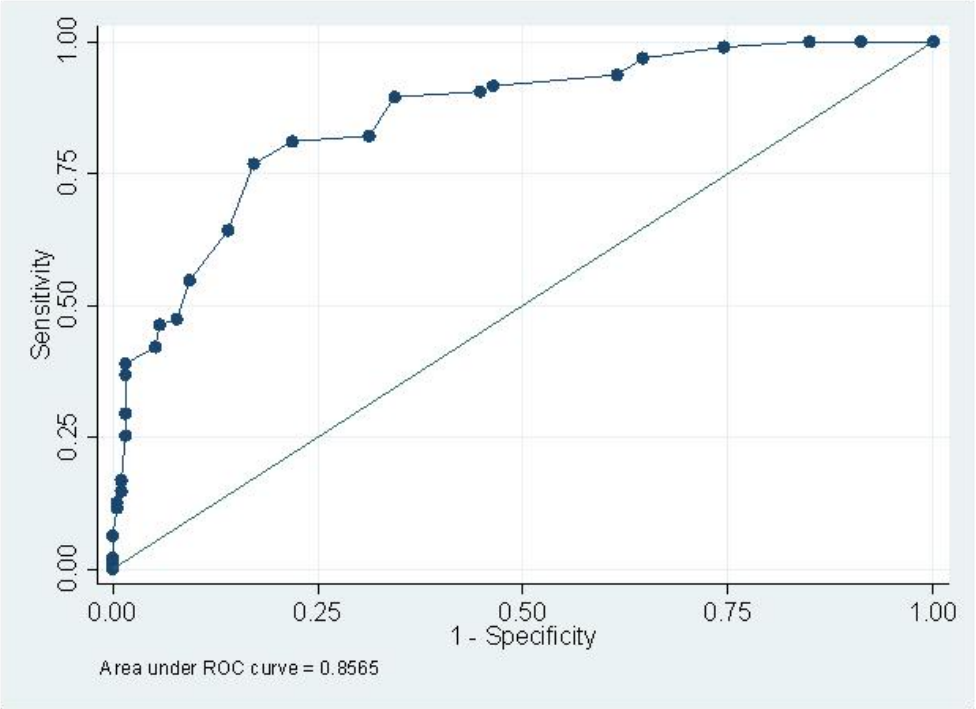

Figure 3 C indices of the training cohort.

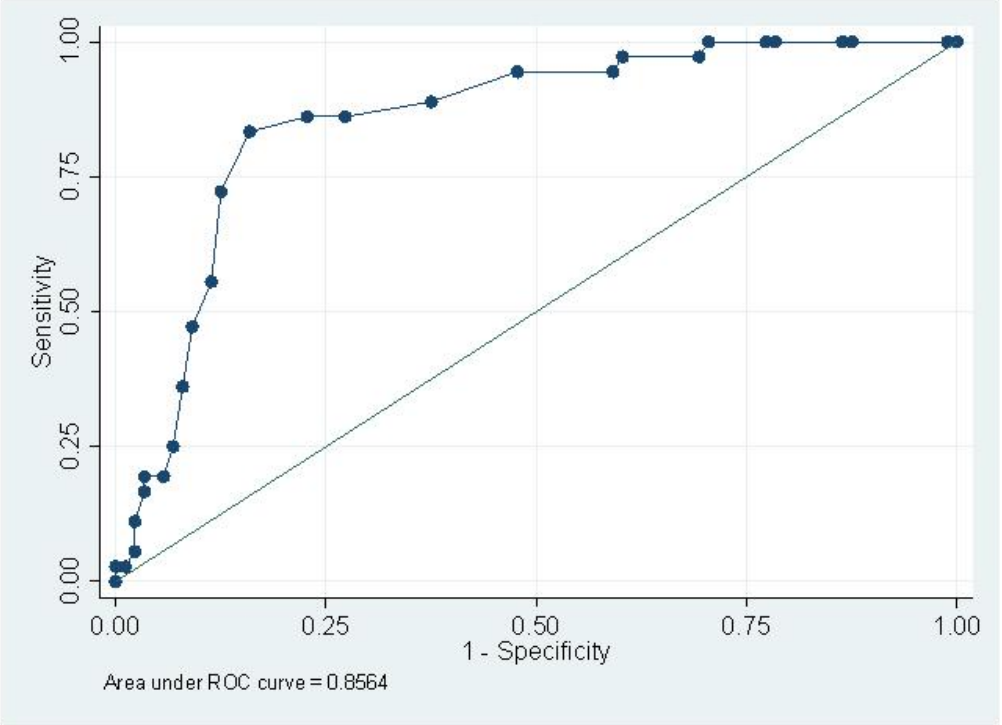

Figure 4 C indices of the validation verification cohort.

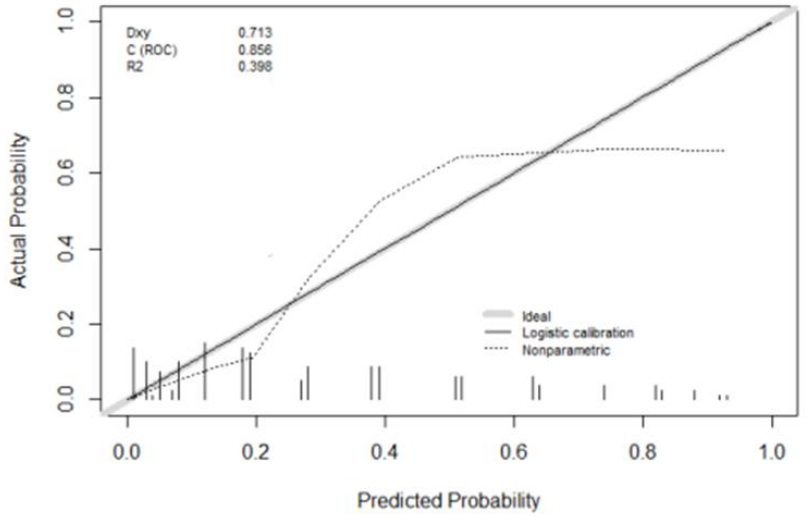

Figure 5 calibration curve

4. Discussion

The treatment of supracondylar fracture disease in children has been a hot topic in pediatric orthopedics. Among them, how to reduce the chance of postoperative complications of supracondylar humeral fractures is a hot study. To the best of our knowledge, predictive models have rarely been applied in the course of fracture studies in children. And we established a comprehensive prognostic score based on 16 variables related to general vital signs and surgical treatment in early childhood supracondylar humerus fractures. Our findings showed that risk factor scores were related to the outcome of postoperative complications and that risk factor scores can be used to guide patients in different risk groups. In addition, our study listed correlations regarding the relationship between general vital signs and postoperative complications. This risk factor prognostic model may accurately assess the likelihood of postoperative complications in children with preoperative supracondylar humerus fractures and provide increasing or downgrading systematic treatment for probable complications from a clinical standpoint. Future validation of this model was warranted.

Based on the risk factors screened by logistic regression, a nomogram model of the sample was constructed. Each risk factor degree had a corresponding score, and the total score was obtained by aggregating the scores of each risk factor. The corresponding linear predictor was found, together with the probability value, which was the probability of complications after a supracondylar fracture of the elbow in a particular child. This helped us to identify patients at "high risk" for supracondylar fractures and to focus attention and guidance on the prevention of related postoperative complications.

Because this is the most common fracture of the elbow joint in children[6-11], appropriate fracture therapy is critical. This is because inappropriate management may lead to fracture-related complications and secondary damage to the child's body, mind, and the child's family. Although there are many methods how to evaluate postoperative function in children with supracondylar humeral fractures, such as by Flynn score and modified Mayo score, differences that may stem from different definitional criteria, differences in study populations, and differences in the orientation of researchers' studies lead to gaps between the applicability of different assessment criteria in the clinical setting and the results of observational studies.

Among the possible complications after surgical treatment of supracondylar fractures of the humerus are nerve injury, pin tract infection, Varus or valgus deformity of the elbow, delayed fracture healing, osteofascial compartment syndrome, ischemic muscle contracture and secondary displacement[12]. Nerve injury can be caused by fracture displacement, where the fracture break can trap the nerve during fracture displacement and produce injury; it can also be due to inappropriate

treatment practices. Most of these nerve injuries are neurological disorders and recover completely. Therefore, surgical exploration of the nerve is rarely required. Valencia et al[13] reported that with long-term conservative treatment of supracondylar fractures of the humerus, the associated nerve injuries recovered completely, e.g., 100% of radial nerve injuries, 87.5% of median nerve injuries, and 25% of ulnar nerve injuries. The average time to recovery of nerve function was 3 months for the radial nerve, 2.5 months for the median nerve, and 5 months for the ulnar nerve. The literature reported postoperative pin tract infections in children with supracondylar humerus fractures in the range of 1% to >25%[14,15]. Most infections were superficial and could be relieved by the removal of the gristle pin and oral antibiotics[16-18]. In rare cases of deep infection or joint involvement, debridement and drainage and intravenous antibiotic therapy usually resolved the problem without significant sequelae[19]. Most authors considered elbow inversion to be the result of fracture deformity healing rather than growth arrest. Angular deformity and rotational deformity are considered to be the cause of elbow inversion. Posterior medial displacement showed higher Baumann values indicating elbow inversion deformity, while posterior lateral displacement showed lower Baumann values indicating elbow valgus [20]. Limb perfusion status can be used as the best reflector of vascular status. According to the presence of a pulse and limb perfusion, the pulse condition can be divided into three conditions: 1) good pulse and good limb perfusion (capillary filling distal to the pulse <3 seconds detected by eco doppler); 2) no pulse but good perfusion in the hand when the so-called pink pulseless hand (disappearance of the pulse, microvascular filling <3 seconds, no distal pulse); 3) disappearance of the pulse and poor perfusion in the hand when the so-called cold hand (pale, cold blood, capillary filling >3 seconds). Ischemia further progresses to necrosis and Volkmann ischemic contracture. There was no satisfactory clinical treatment for such complications[21]. A survey by the British Society for Paediatric Orthopaedic Surgery revealed that 60% of surgeons supported continued observation if the forearm remained pulseless but well perfused[21].

Predictive models were not widely used in fractures in children. We conducted a systematic and thorough analysis of general vital signs and related surgical treatment measures in the current study and discovered many main findings: 1) We obtained the imbalance status of age, fracture type, and nerve injury, which were the basic physical signs, may affect disease progression and lead to postoperative related complications. 2) In the prediction of the occurrence of postoperative complications in children with supracondylar humerus fractures, gender was used as a protective factor of the occurrence of postoperative complications. Consistent with the results of relevant studies. In a five-year follow-up study of more than 63,000 children with supracondylar humerus fractures, there was no statistically significant difference in the incidence of supracondylar fractures by gender[22]. 3) In previous studies in the literature, the use of a combination of preoperative radiographs and postoperative elbow function scores was found to be effective in the management of patients. Our current study showed that the type of fracture was an independent risk factor regarding postoperative complications. If a child developed a supracondylar humeral fracture, clinicians could use this visual scale to assess the risk of postoperative complications in combination with other relevant scores as well as X-rays to further prevent postoperative complications.4) The main finding of this study: independent prognostic factors identified using COX regression analysis in the training cohort contained six readily available clinical variables, and in the validation, the cohort contained three readily available clinical variables allowing for the prediction of the associated risk. The corresponding column line graph model was developed using COX regression, and validation of the nomogram confirmed the good risk prediction performance of the model. Interestingly, our study demonstrated that increasing age, as determined by the optimal cutoff value, was an important risk factor for the development of postoperative complications.

Medical nomograms provided predictive information tailored to the individual by creating a concise graph that generates numerical probabilities of clinical events[22-26], and in this study, we first identified independent predictors of the occurrence of postoperative fracture complications with parameters that suggested older than eight years, fracture type, and nerve injury.

The established nomogram showed moderate discriminatory power and was further externally validated. Overall, this predictive model allowed pediatricians to use the nomogram to assess the risk stratification of the probability of postoperative complications in children with supracondylar humeral fractures.

We acknowledged that this study had some limitations. First, the nature of this study was retrospective and there may be selection bias in the selection of the target population; second, a nomogram model based mainly on baseline levels of vital signs was established. Since these vital signs cannot be maintained at a certain level throughout the study period, this may lead to imprecise results compared to the normal range and may result in differences between predicted and observed values; third, all patients in this study were children who underwent surgery at the same hospital. To reduce error, a prospective trial with a large number of patients recruited from multiple institutions would help to address these limitations.

5. Conclusion

Taken together, the results suggested that clinical characteristics can be used as independent risk predictors for the development of complications after supracondylar fracture surgery. Combining vital signs and clinical risk factors into an easy-to-use nomogram was more likely to predict the probability of complications in patients after supracondylar fracture surgery, leading to more appropriate treatment modalities.

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Abbreviations

SCHF: Supracondylar humeral fractures.

CRPP: Closed reduction and percutaneous pinning.

ROC: the Receiver operating characteristic curve.

AUC: the Area under the curve.

DCA: decision curve analysis.

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