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Original Article

Risk factors influencing postoperative outcome of arthroscopic rotator cuff repair and construction of a nomogram prediction model

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Abstract: Objective: To investigate the risk factors influencing the postoperative outcome of arthroscopic rotator cuff repair (ARCR) and develop a nomogram prediction model. Methods: A retrospective study was conducted on 302 patients who underwent ARCR from January 2019 to August 2023. Patients were categorized into two groups: a control group with 150 patients showing good recovery and an observation group with 152 patients exhibiting poor recovery. Relevant clinical data were collected and statistically analyzed. A nomogram model was constructed based on the results of multivariate logistic regression analysis. The model's accuracy, discrimination, and clinical utility were evaluated using calibration charts, AUC, c-index, and decision curve analysis. Internal validation was performed through self-random sampling. Results: Univariate and multivariate regression analysis identified having a frozen shoulder, large rotator cuff tear, increased intraoperative rivet use, diabetes, and traumatic tear as predictive risk factors for poor postoperative outcomes. These factors were utilized to develop a clinical predictive nomogram. The nomogram model demonstrated excellent predictive accuracy for poor postoperative outcomes, both internally and externally. The unadjusted concordance index (C-index) was 0.793 [95% confidence interval (CI), 0.825-0.995]. The AUC for the nomogram was 0.788. Decision curve analysis revealed that the predictive model was clinically useful when the threshold probability ranged from 20 to 60%. Conclusion: The presence of a frozen shoulder, large rotator cuff tear, increased intraoperative rivet use, diabetes, and traumatic tear elevate the risk of suboptimal outcomes following ARCR. Conversely, having a higher preoperative University of California at Los Angeles Shoulder Rating Scale score mitigates this risk. This study introduces a novel nomogram model, exhibiting relatively high accuracy, which enables clinicians to precisely assess the postoperative adverse risk among patients with rotator cuff injuries requiring arthroscopic repair at the outset of treatment.

Keywords: Postoperative outcome, arthroscopic rotator cuff repair, risk factors, nomogram

Introduction

Rotator cuff injury, characterized by one or more tendon tears or detachment from the humerus, is the leading cause of shoulder pain, predominantly affecting individuals over 40 years of age with a mean age of 55 [1-3]. Typical symptoms include nocturnal shoulder pain and dysfunction, causing significant psychological and lifestyle burden. Conservative management is the initial approach, but for those who fail to respond, arthroscopic rotator cuff repair (ARCR) remains the preferred surgical option [4-7]. ARCR offers reduced postoperative pain, faster recovery, and fewer complications compared to traditional open surgery.

Arthroscopic single-row rivet repair, a method for in-situ suturing of the rotator cuff in ARCR, offers patients lower operation costs and broader accessibility compared to double-row rivet repair. As orthopedic surgeons' understanding of rotator cuff injuries deepens, the number of diagnosed cases and those requiring arthroscopic surgery is rising. Inevitably, some patients may experience unsatisfactory shoulder function recovery following arthroscopic single-row rivet repair. However, the factors

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influencing the clinical outcomes of this procedure remain incompletely understood. Previous studies have primarily focused on age, body mass index, diabetes, fat infiltration in the subscapularis and infraspinatus, symptom duration, bone mineral density, tear length, tear width, tear area, retraction, critical shoulder angle, shoulder brachial septum, the distance from tendon junction to glenoid joint, operation time, and the management of the long head tendon of the biceps brachii [8-12]. However, rotator cuff re-tear and healing do not always reflect the prognostic outcomes in terms of pain and function. Ball et al. [13] examined patients who underwent ARCR using magnetic resonance arthrography at least six months postoperatively. Notably, even with 65.6% of patients exhibiting interstitial division and/or stratification, 14.6% displayed significant partial thickness tears (> 50%). Remarkably, these findings had no impact on outcomes, as measured by the ASES score and patient satisfaction. Similarly, Shim et al. [14] observed improved shoulder function in patients with compromised rotator cuff integrity post-ARCR. Consequently, investigating the factors influencing clinical outcomes following ARCR in rotator cuff injury in patients appears crucial. Currently, there is a paucity of clinical evaluation and prediction models that accurately foretell the postoperative effects of ARCR in these patients, which could significantly benefit both clinicians and patients.

Therefore, we analyze the risk factors influencing the postoperative outcome of ARCR, establish independent predictors, assess their predictive power, and construct a nomogram. This nomogram could provide a theoretical framework for optimizing clinical outcomes following ARCR.

Methods and materials

Study design and participant selection

This retrospective analysis was conducted at Dongying People's Hospital from January 2019 to August 2023. The study protocol was thoroughly reviewed and approved by the medical ethics committee of Dongying People's Hospital, ensuring compliance with ethical standards.

Inclusion and exclusion criteria

Inclusion criteria: 1) patients who underwent arthroscopic single-row rivet rotator cuff repair at Dongying People's Hospital between January 2019 and August 2023; 2) patients aged 18 years and above; 3) patients with a confirmed diagnosis of rotator cuff tear under arthroscopic examination [15]; and 4) patients with comprehensive clinical records. Exclusion criteria: 1) patients with shoulder fractures, including those involving the glenoid, humerus, or clavicle; 2) patients with concurrent shoulder and labrum injuries, severe osteoarthritis, or shoulder joint tumors; 3) patients with a prior history of shoulder surgery; and 4) patients with incomplete clinical data.

Operative methods

Under anesthesia to ensure patient comfort and immobility of the shoulder, the surgeon proceeds with a delicate incision, enabling the insertion of an arthroscope (Smith & Nephew, 72203025). This arthroscope, once positioned within the shoulder joint, provides a clear visualization of the internal structures on a monitor. Utilizing precision instruments (Stryker, 5100-10-120), the surgeon meticulously repairs the torn rotator cuff. This may entail the excision of damaged tissue, the reattachment of the tendon to the bone, or a combination of both procedures. Upon completion of the repair, the incision is securely closed with sutures or surgical tape.

Data collection

Collect and document patient demographics, including gender, age, affected side, disease duration, traumatic etiology of rotator cuff tear, and comorbidities such as dyslipidemia, hypertension, and diabetes. Ensure that information on concomitant frozen shoulder is also recorded. Preoperatively, all patients underwent shoulder joint radiography in the anterior and supraspinatus outlet positions, in addition to MRI. Document surgical details, including the number of rivets used, tear type (full-thickness or partial), and the presence of a large rotator cuff tear. Specify the treatment methods for the long head of the biceps tendon (LHBT), including no treatment, simple excision, excision with fixation, or excision with transposition fixation. Define dyslipidemia as a fasting blood test result of total cholesterol ≥ 6.19 mmol/l or triglyceride ≥ 2.27 mmol/l. Traumatic rotator cuff tears are diagnosed when shoulder pain onset is attributable to a specific event capable of causing such a tear [16]. Large rotator cuff tears are defined as defects greater than 5 cm or involving two or more tendons [17]. Finally, patients are classified into two groups based on the University of California at Los Angeles Shoulder Rating Scale (UCLA) score at the final postoperative follow-up: a good recovery group with scores ≥ 29 points and a poor recovery group with scores < 29 points [18].

Statistical analysis

Using SPSS 22.0 statistical software, the collected data were thoroughly analyzed. Quantitative data were expressed as mean ± standard deviation, while categorical data were represented by the number of cases or percentages. The Shapiro-Wilk test was applied to assess data normality, separately for all patients and the subset of patients aged ≥ 65 years, both pre- and post-operatively at the final follow-up. Paired-sample t-tests were employed to compare within-group differences, assuming normal distribution; otherwise, the Wilcoxon rank-sum test was used. Univariate binary logistic regression analysis encompassed variables such as gender, age, disease duration, traumatic etiology, frozen shoulder, hypertension and diabetes history, dyslipidemia, number of rivets used, tear type (full-thickness or partial), size of rotator cuff tear, specific LHBT treatment, preoperative VAS score, and preoperative UCLA score.

Subsequently, multivariate binary logistic regression analysis was conducted on the selected risk factors. Notably, the "cut-off fixation" and "cut-off transposition fixation" categories in LHBT treatment were merged into a single "cut-off fixation" category, simplifying the four original LHBT treatment methods into three: untreated, simple cut-off, and cut-off fixation. This allowed for a more concise and focused analysis while maintaining the integrity of the data. When P < 0.05, the difference was deemed statistically significant. To establish a risk nomogram model predicting poor postoperative outcomes in patients with rotator cuff injuries treated by ARCR, R software (version 4.2.1) was utilized. Additionally, the calibration curve, receiver operating characteristic (ROC) curve, and decision curve analysis were generated to assess the model's performance. The cut-off values for continuous variables were determined using SPSS. The calibration curve illustrates the agreement between the nomogram's predicted outcomes and the actual results. In an ideally calibrated nomogram, the calibration curve aligns with the 45-degree line [19]. The area under the ROC curve (AUC) and the c-index were calculated to evaluate the model's predictive ability. Similar to AUC, the c-index is particularly suitable for assessing predictive models [20]. A higher c-index indicates a more accurate prognostic model. Internal validation of the nomogram was conducted through random sampling with 1000 bootstrap replications to derive a bias-corrected c-index. Furthermore, by analyzing the decision curve and quantifying the net benefit across different threshold probabilities in the ARCR-treated rotator cuff injury cohort, the clinical utility of the risk nomogram for predicting poor postoperative outcomes was determined [21].

Results

Comparison of clinical characteristics

Based on the UCLA score at the final follow-up, patients were stratified into two groups: those scoring ≥ 29 points comprised the good recovery group (control group), while those scoring < 29 points comprised the poor recovery group (observation group). Ultimately, the control group consisted of 150 patients, and the observation group contained 152 patients. As **Table 1** demonstrates, several factors such as traumatic tear, diabetes, dyslipidemia, concomitant frozen shoulder, full-thickness tear, massive rotator cuff tear, preoperative UCLA score, and the number of intraoperative rivets exhibited statistical significance between the two groups (P < 0.05). However, there were no significant differences in age, body mass index, gender, disease duration, hypertension, LHBT treatment method, or preoperative visual analogue scale (VAS) pain score (P > 0.05).

Univariate and multivariate regression analysis

As presented in **Table 2**, the Kaplan-Meier method was employed for univariate analysis,

Table 1. Comparison of clinical data between the two groups

Clinical parameters	Control Group (n=150)	Observational group (n=152)	t/x^2	*P*
Age	46.8±6.1	49.4±3.9	4.847	0.251
Body mass index	21.3±9.8	22.3±5.7	2.078	0.122
Sex			4.49	0.43
Male	60 (40.0%)	68 (44.7%)		
Female	90 (60.0%)	84 (55.3%)		
Disease duration	13.55±28.65	14.84±39.24	0.093	0.761
Traumatic tear	100 (66.7%)	72 (47.4%)	8.533	0.022
Hypertension	30 (20.0)	25 (16.4)	0.084	0.772
Diabetes	11 (7.3)	20 (13.2)	5.283	0.032
Dyslipidemia	30 (20.0)	46 (30.3)	7.930	0.021
Combination of frozen shoulder	11 (7.3)	33 (21.7)	4.831	0.018
Full layer tear	136 (90.7)	134 (88.2)	8.831	0.008
Huge rotator cuff tear	9 (6.0)	76 (50.0)	10.004	0.003
LHBT processing method			1.837	0.329
Unprocessed	113 (75.3)	60 (39.5)		
Cut off	25 (16.7)	39 (25.7)		
Cut and fix	12 (8.0)	69 (45.4)		
Preoperative VAS translation score (points)	6.38±1.61	6.34±1.65	2.287	0.219
Preoperative UCLA score (points)	13.67±2.38	12.69±3.01	7.430	0.011
Number of intraoperative rivets	1.98±1.04	3.49±1.54	8.175	0.009

LHBT: long head of the biceps tendon; UCLA: University of California at Los Angeles Shoulder Rating Scale.

revealing that traumatic tear, diabetes, coexistence of frozen shoulder, LHBT (long head of biceps tendon) management, the number of rivets used, and preoperative UCLA score were significantly associated with an increased risk of poor postoperative outcomes following ARCR ($P < 0.05$). Subsequently, these significant single factors were further analyzed using the Cox proportional hazards regression model. The results indicated that the coexistence of having a frozen shoulder, massive rotator cuff tear, higher number of intraoperative rivets, diabetes, and traumatic tear were independent predictors of unfavorable postoperative outcomes following ARCR.

Development of nomogram model

The risk factors associated with poor postoperative outcomes of ARCR were incorporated into a prediction model developed using R software (version 3.6.3). The cumulative risk score, derived from the sum of the integral of each factor, served as the risk value for predicting poor postoperative outcomes of ARCR (**Figure 1**). The nomogram formula is as follows:

Poor Postoperative Nomogram = 5.478 + 0.592 × Combination of Frozen Shoulder + 0.668 × Massive Rotator Cuff Tear + 0.764 × Number of Intraoperative Rivets + 0.418 × Diabetes + 0.602 × Traumatic Tear + 0.412 × Preoperative UCLA Score.

Validation of a nomogram model

The unadjusted C-index of the nomogram was 0.793 (95% confidence interval, 0.825-0.995). **Figure 2** depicts the calibration plot of the nomogram, which demonstrates its predictive accuracy. Additionally, the AUC for the nomogram was 0.788, with a *p*-value of 0.0243 (**Figure 3**). These findings indicate that the nomogram model exhibits good discriminative ability and consistency in predicting the risk factors associated with poor postoperative outcomes of ARCR.

Decision curve analysis

The decision curve analysis presented in **Figure 4** reveals that the model's validity is enhanced when the threshold probability for a poor postoperative effect of ARCR ranges from

Table 2. Univariate and multivariate regression analysis

Variable	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P	OR (95% CI)	P
Age				
≥ 65	1.751 (0.487-2.648)	0.794	1.987 (0.844-3.287)	0.887
< 65	1.000			
Gender				
Female	1.364 (0.678-2.384)	0.524	1.783 (0.587-2.398)	0.849
Male	1.000			
Disease duration	1.024 (0.988-1.248)	0.890	1.332 (0.478-1.938)	0.493
Traumatic tear	3.507 (0.824-2.259)	0.009	3.568 (1.607-9.608)	0.013
Hypertension	0.814 (0.354-1.821)	0.451	2.094 (1.092-2.398)	0.099
Diabetes	2.013 (1.712-4.925)	0.034	3.927 (1.647-9.678)	0.007
Dyslipidemia	1.563 (0.748-3.488)	0.172	1.087 (0.857,1.387)	0.221
Combination of frozen shoulder	3.927 (1.647-9.678)	0.007	4.568 (1.647-9.678)	0.023
Full layer tear	0.984 (0.324-1.249)	0.827	1.207 (0.887,1.687)	0.912
Huge rotator cuff tear	16.437 (6.829-29.279)	0.942	4.224 (1.298-12.791)	0.034
LHBT processing method				
Unprocessed	1.000		1.000	-
Cut off	2.632 (1.174-6.768)	0.028	1.548 (0.643-5.688)	0.641
Cut and fix	6.267 (4.636-15.526)	< 0.001	2.568 (1.647-9.678)	0.084
Number of rivets (pieces)	3.037 (2.385-6.788)	< 0.001	2.108 (1.674-3.728)	0.001
Preoperative VAS translation score (points)	1.227 (0.677-2.358)	0.342	1.741 (1.284,2.387)	0.210
Preoperative UCLA score (points)	0.572 (0.437-1.782)	< 0.001	0.668 (0.575-1.878)	0.028

LHBT: long head of the biceps tendon; VAS: visual analogue scale; UCLA: University of California at Los Angeles Shoulder Rating Scale.

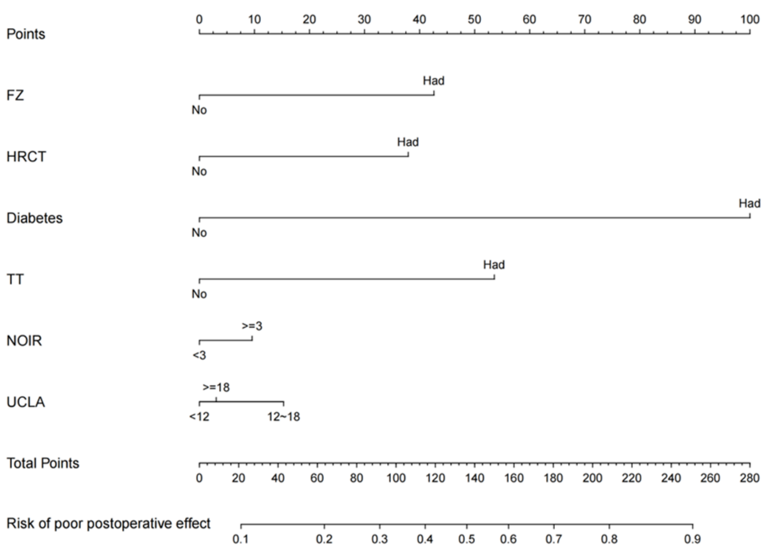

Figure 1. The nomogram for predicting the risk of the poor postoperative effect of arthroscopic rotator cuff repair. FZ: frozen shoulder; HRCT: huge rotator cuff tear; TT: traumatic tear; NOIR: number of intraoperative rivets; UCLA: University of California at Los Angeles Shoulder Rating Scale.

20% to 60%. This predictive model is thus deemed suitable for clinical application.

Discussion

Our study identified several factors that influence shoulder joint dysfunction in patients with rotator cuff injuries undergoing ARCR. Specifically, the presence of a combined frozen shoulder, a massive rotator cuff tear, the number of rivets required during surgical repair, preoperative UCLA score, traumatic tear, and diabetes mellitus were found to be significant. Of these, a combination of frozen shoulder, a massive rotator cuff tear, and an increased number of rivets during surgical repair were associated with a significantly higher risk of adverse postoperative outcomes. Conversely, a higher preoperative UCLA score indicated a lower risk of poor postopera-

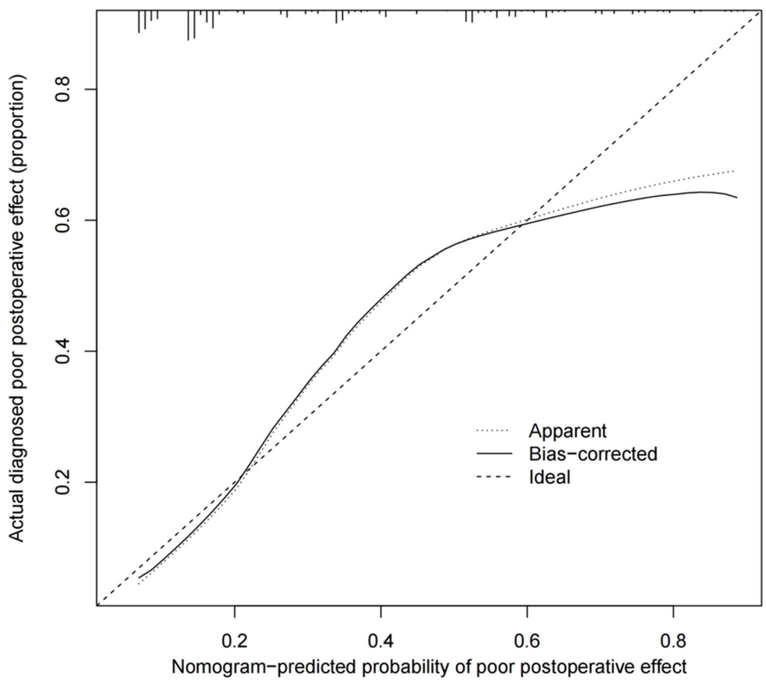

Figure 2. The calibration curves for predicting the risk of the poor postoperative effect of arthroscopic rotator cuff repair.

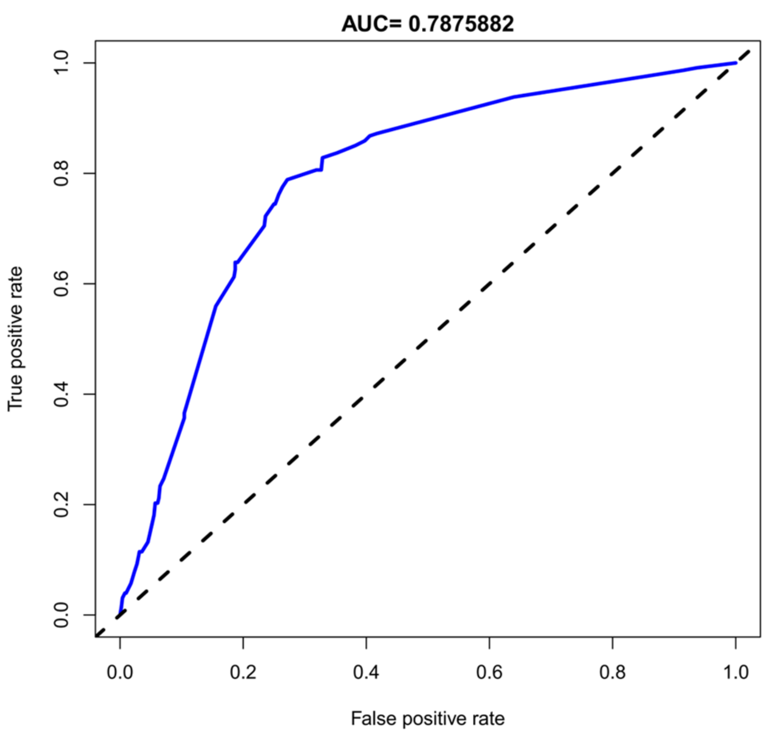

Figure 3. ROC curves for predicting the poor postoperative effect of arthroscopic rotator cuff repair.

tive outcomes among patients treated arthroscopically for rotator cuff injuries. These findings align with previous studies by Haviv et al. [22], who reported that larger rotator cuff tear size predicts poor shoulder function after ARCR. Similarly, Plachel et al. [23] and Jenssen et al. [24] found that a higher preoperative shoulder function score predicts improved shoulder function following ARCR, consistent with our observations.

Patients with huge rotator cuff tears often exhibit significant preoperative pain and dysfunction due to the extensive tear area or involvement of two or more tendons. In such cases, the surgical procedure is typically more complex and time-consuming compared to repairs for smaller tears, and complete coverage of the footprint area may not always be achievable [25]. Additionally, the increased number of rivets utilized during surgery often reflects more extensive and complex rotator cuff injuries. Consequently, even skilled orthopedic surgeons encounter challenges in accurately predicting the postoperative outcomes for patients with massive rotator cuff tears.

Consistent with this, Lee et al. [26] discovered in a cohort study that the initial size of the rotator cuff tear serves as an independent risk factor for rotator cuff re-tear. Therefore, clinicians should exercise caution when evaluating preoperative MRI scans that indicate extensive or multi-tendon involvement, perform thorough preoperative planning, and develop tailored rehabilitation programs for these patients.

Frozen shoulder, a musculoskeletal condition marked by glenohumeral joint pain and limited range of motion, predominantly affects middle-

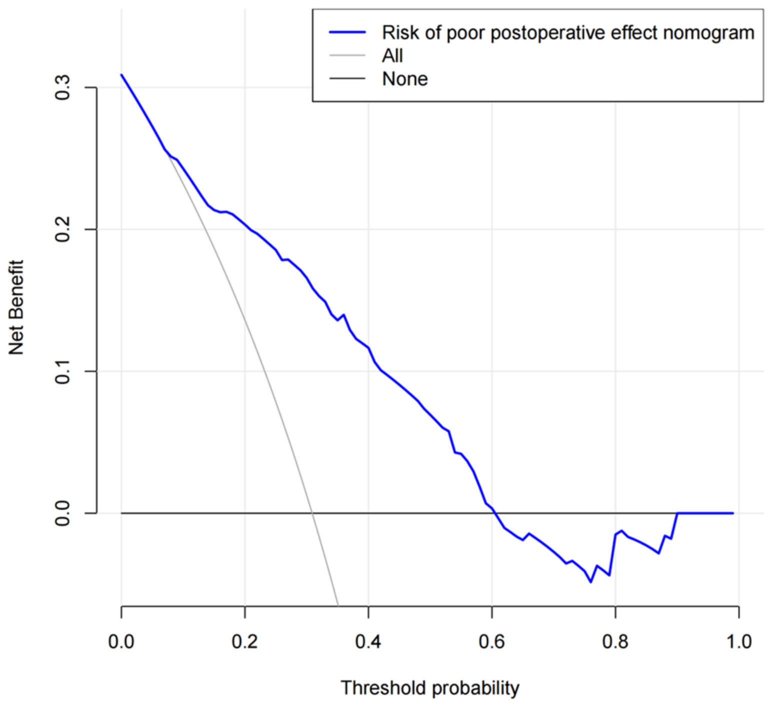

Figure 4. Decision curve analysis for the nomogram.

aged women [27]. Characterized as aseptic inflammation of the shoulder's surrounding soft tissue, it exhibits a degree of self-limitation, albeit with an unclear etiology. Clinically, some cases of rotator cuff injury are ultimately diagnosed due to severe shoulder dysfunction [28]. Notably, preoperative shoulder stiffness has been identified as a risk factor for postoperative stiffness [29]. A retrospective cohort study by Jeong et al. [30] further revealed that rotator cuff tears combined with frozen shoulder negatively impact most functional outcomes, including range of motion, at 6 months and 1 year post-ARCR.

Given this, it is imperative to give due consideration to patients with rotator cuff injuries coupled with frozen shoulder before surgery. Thorough preoperative diagnosis is crucial to avoid misdiagnosis, and patients should be encouraged to actively participate in postoperative rehabilitation training.

To aid clinicians in predicting the clinical prognosis of patients with rotator cuff injuries undergoing ARCR, we developed and validated a nomogram prediction model for assessing the risk of adverse postoperative outcomes. This study marks the first application of nomograms in forecasting the prognosis of patients treated with arthroscopic rotator cuff repairs. Nomograms are widely utilized as prognostic prediction tools in oncology, offering a user-friendly digital interface, high accuracy, and clarity in prognosis assessment, thereby facilitating better clinical decision-making [31].

Through multivariate regression analysis, we identified the presence of frozen shoulder, large rotator cuff tears, the number of rivets used, and preoperative UCLA scores as the constituent factors of our nomogram. These factors are readily accessible. Clinicians can simply add the scores for each variable to obtain a total score and subsequently identify the corresponding risk value, thus estimating the risk of adverse effects post-ARCR for patients with rotator cuff injuries. This streamlined approach enhances the ease of using nomograms and facilitates clinicians' utilization of this model to predict the postoperative adverse risk for patients undergoing ARCR. Furthermore, our study offers a precise predictive tool for patients with rotator cuff injuries post-ARCR. Internal validation within the cohort demonstrates excellent discrimination and calibration capabilities. Notably, the positive C-index obtained from our random sampling verification suggests that the nomogram can be widely and precisely applied to other samples. Anticipating the adverse risk in these patients prior to ARCR enables clinicians to take proactive intervention measures and encourages patients to adjust their lifestyle accordingly, ultimately benefiting both patients and doctors.

However, this study has limitations. Firstly, as a single-center study, the selected samples may not fully represent the general population. Secondly, as a retrospective study, some influential factors could not be accounted for, resulting in the analysis of risk factors for adverse outcomes after ARCR being incomplete. Additionally, the nomogram model in this study is only internally validated and requires further external validation for broader support. In future research, we aim to conduct a multicenter, randomized controlled study to comprehensively investigate the factors influencing the clinical outcomes of arthroscopic single-row rivet repair.

The combination of frozen shoulder, massive rotator cuff tears, a greater number of intraoperative rivets, diabetes, and traumatic tears elevates the risk of suboptimal outcomes following ARCR. This study introduces a novel nomogram model with considerable accuracy, enabling clinicians to precisely evaluate the postoperative adverse risk for patients with rotator cuff injuries requiring arthroscopic repair at the outset of treatment. By assessing individual risk, clinicians can proactively implement more favorable intervention measures during all stages of the ARCR process.

Disclosure of conflict of interest

None.

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