Article

# Risk Factors Analysis and Prediction of Rotator Cuff Tears: A Retrospective Study

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AIM: Rotator cuff tears (RCTs) are a major cause of shoulder pain and disability, affecting millions worldwide. Understanding the risk factors and developing reliable predictive measures for RCTs is essential for early diagnosis, targeted prevention, and effective treatment of this patient population. This study seeks to enhance our understanding by analyzing the acromiohumeral distance (AHD) and Constant-Murley Score (CMS) in patients with and without RCTs, thereby aiding the development of a predictive model aimed at improving clinical outcomes and prevention strategies in rotator cuff pathology.

METHODS: This retrospective analysis involved 201 patients with shoulder pain, categorized into RCT (n = 72) and no RCTs (N-RCTs, n = 129) groups based on Magnetic Resonance Imaging (MRI) findings. We compared demographics, AHD, CMS, and rotator cuff status between groups and utilized logistic regression for identifying RCT predictors, leading to the development of a multifactorial predictive model.

RESULTS: The mean AHD was 6.60 ± 1.12 mm. The RCT group showed a marginally higher AHD than the N-RCT group ($p$ = 0.669). CMS scores were significantly lower in the RCT group ($p < 0.001$). Dominant side involvement (Odds Ratio (OR) 2.244), type III acromion (OR 6.106), and lower CMS (OR 0.938) significantly correlated with RCTs. The predictive model demonstrated an area under the curve (AUC) of 0.701 for RCT diagnosis.

CONCLUSIONS: Reduced CMS, dominance of the affected side, and type III acromion emerged as key risk factors for RCTs. Our predictive model, incorporating these factors, holds promise for RCT diagnosis, with future studies needed for further validation.

**Keywords:** rotator cuff tears; risk factors analysis; orthopedic predictive modeling

## Introduction

Rotator cuff tears (RCTs) constitute a significant clinical concern in shoulder pathologies. They often necessitate surgical intervention due to their substantial contribution to disability and pain. While various etiologies can contribute to shoulder pain, RCTs are particularly noteworthy for their severity, frequently emerging as the culmination of subacromial pain syndrome (SAPS) [1–3]. The incidence of RCTs in SAPS cases is substantial, affecting up to half of all patients [4, 5]. The importance of early diagnosis for preventing progression has been emphasized due to the severe impact of these tears on patient outcomes [6]. A recent study identified genetic markers and a history of shoulder trauma as potential factors for RCT development [7]. Understanding the pathogenesis of RCTs, including their relationship with acromiohumeral distance (AHD) and the Constant-Murley Score (CMS), is crucial for effective diagnosis and management strategies.

It has long been thought that a reduced subacromial space and the resulting mechanical impingement are critical contributors to RCTs through their influence on the acromiohumeral distance [8]. Despite surgical strategies like acromioplasty aiming to modify AHD for rotator cuff repair [9, 10], recent evidence challenges this conventional understanding of AHD's role in SAPS and RCTs. Studies have demonstrated a lack of significant differences in AHD between SAPS patients and control groups. Notably, a study suggests a possible correlation between SAPS symptoms and the thickening of the supraspinatus tendon, potentially indicating alternative mechanisms at play [11]. This emerging body of evidence necessitates a reevaluation of the significance attributed to AHD in the context of RCTs.

Furthermore, the CMS questionnaire, a well-established and comprehensive tool for assessing shoulder function, provides valuable insights into the functional impact of RCTs [12]. Lower CMS scores observed in RCT patients directly correlate with the tear's severity, manifesting as pain, limitations in function, and a reduced range of motion. However, the existing literature offers limited exploration

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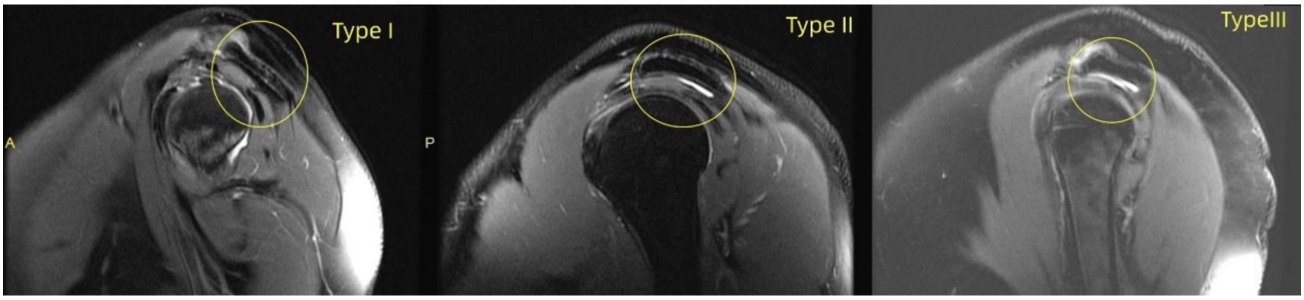


**Fig. 1. Three typical acromion shapes observed on Magnetic Resonance Imaging (MRI).** Each of the three acromion forms is shown in the yellow circle.

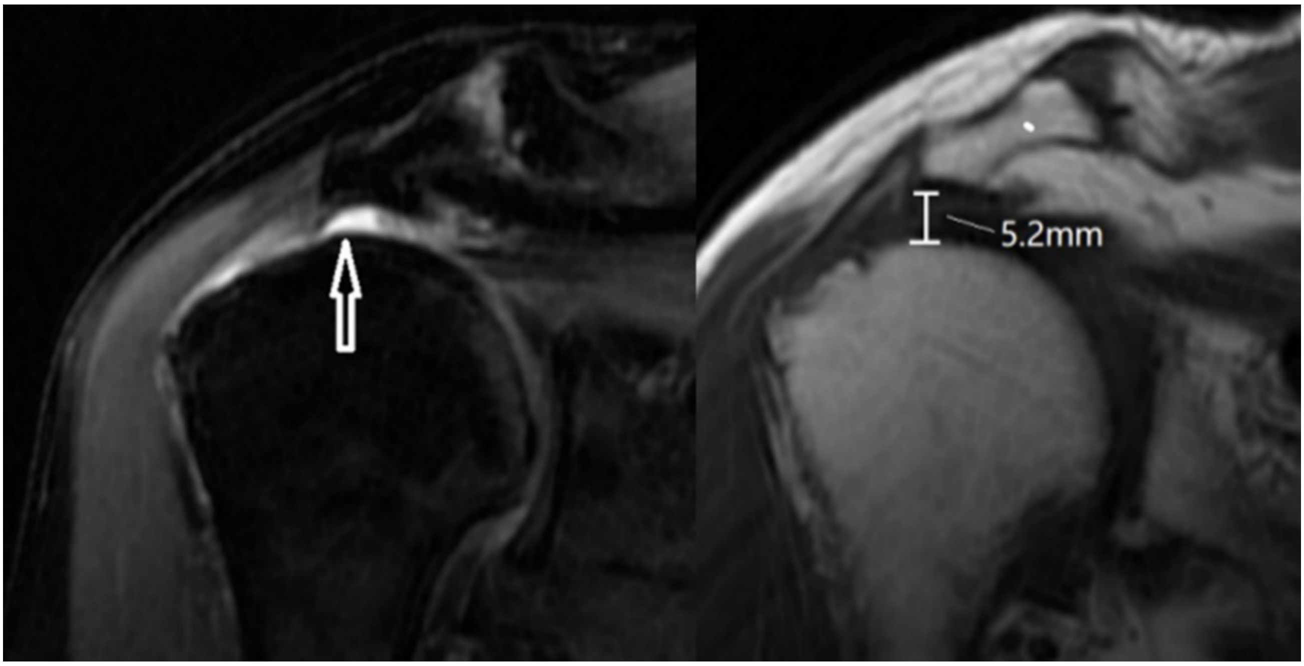


**Fig. 2. Acromiohumeral distance (AHD) measurement method.** The shortest distance between the subchondral bone plate of the humeral head and the cortical margin of the acromion was measured on coronal oblique T1-weighted MRI images (as shown in the left image). Additionally, the extent of the supraspinatus tendon injury was assessed on coronal oblique MRI proton density-weighted (PD-weighted) images. A full-thickness tear of the distal supraspinatus tendon is indicated by the arrow in Fig. 2.

of the direct relationship between AHD and CMS scores. A previous study has exhibited limited ability to establish a clear link between changes in AHD and improvements in functional outcomes [13].

This study endeavors to address these knowledge gaps by comprehensively examining the differences in AHD and CMS scores between patients with and without RCTs. We hypothesize that significant variations in AHD and CMS scores are valuable indicators of RCTs, reflecting the underlying biomechanical and functional impairments associated with these tears. By elucidating the intricate relationship between AHD, CMS, and RCTs, this study aims to illuminate the complex interplay of these factors in rotator cuff pathology, ultimately informing and refining clinical practice.

## Materials and Methods

*Study Population*

This study retrospectively analyzed patients admitted to our hospital with shoulder pain syndrome between March 2019 and February 2022. Inclusion Criteria: (1) Individuals aged 18 years or older. (2) Confirmed Magnetic Resonance Imaging (MRI) evidence of rotator cuff pathology, which includes edema, hemorrhage, degeneration, or tears in the supraspinatus, infraspinatus, and/or subscapularis tendons. Exclusion Criteria: (1) Incomplete patient data that could compromise the integrity of our analysis. (2) Trauma-induced rotator cuff injuries, as the mechanism of injury could differ significantly from non-traumatic cases. (3) Other major shoulder joint pathologies such as severe osteoarthritis or rheumatoid arthritis, which could confound the analysis of rotator cuff tears. (4) Patients who did not undergo an MRI at our facility, ensuring consistency in the imaging methodology and interpretations across all cases. Data on gender, age, affected shoulder, dominant side, and duration of symptoms were collected from medical records and analyzed.

*Classification of Acromion Type*

Acromion type was categorized based on the morphology observed in MRI using a previously established classification system [14]. This system identifies three distinct types: Type I (flat), Type II (arc-shaped), and Type III (hooked) (Fig. 1). Variations in acromion morphology have been linked to mechanical impingement and rotator cuff pathology, highlighting the importance of this classification. To ensure reliable assessment, two experienced musculoskeletal radiologists independently reviewed the MRI images. Any discrepancies in their classifications were resolved through consensus discussion.

*Measurement of AHD*

MRI assessments were conducted using 1.5 Tesla (T) MRI scanners (GE Signa HDxt) equipped with a dedicated shoulder coil. AHD was measured following the method described by Siow *et al*. [15] using the picture archiving and communication system (PACS) from the radiology department (GE PACS Workstation). To ensure measurement reliability, an averaged value was obtained from independent assessments by a rehabilitation physician specializing in shoulder surgery and an experienced musculoskeletal radiologist. AHD was quantified in millimeters from coronal oblique T1-weighted images, focusing on the shortest distance between the subchondral bone plate of the humeral head and the cortical margin of the acromion (as illustrated in Fig. 2). The presence of a rotator cuff tear was determined by an orthopedic surgeon based on a pre-established criterion: tear thickness exceeding 50% or full thickness (Fig. 2).

*CMS Assessment*

We utilized the CMS as a comprehensive outcome measure for evaluating functional limitations in patients with shoulder pathologies. The CMS is a widely recognized, standardized tool that combines objective measures and patient-reported outcomes to assess overall shoulder function. It encompasses several domains, including pain, activities of daily living (ADLs), range of motion, and strength, providing a holistic view of a patient's functional capacity. However, we encountered challenges with strength measurements due to difficulties maintaining the required 90-degree shoulder abduction position, leading to inconsistent results. To ensure data reliability and consistency, we adopted a modified version of the CMS as described in the literature [16]. This modification excluded the strength component, resulting in a maximum possible score of 75 points compared to the standard 100. This adjustment reflects the absence of the strength domain, which typically contributes 25 points to the full CMS.

*Diagnostic Criteria*

MRI was chosen as the preferred diagnostic modality due to its non-invasive nature and ability to provide detailed visualization of soft tissues. MRI is particularly advantageous for identifying RCTs given that its high-resolution images enable the differentiation between healthy and pathologic tissues with high accuracy. To ensure consistent and reliable diagnoses, we employed standardized shoulder imaging protocols. Our protocol utilized a 1.5 Tesla (T) MRI scanner equipped with a dedicated shoulder coil. Key imaging sequences included coronal oblique T1-weighted and proton density-weighted (PD-weighted) images. The diagnostic criteria for identifying RCTs focused on detecting any discontinuity or retraction of the tendon fibers. Tears were then classified based on their morphology as partial-thickness or full-thickness tears, as described in the literature [17]. Notably, a full-thickness tear was specifically defined as the complete severance of the tendon from the bone, demonstrably visible across multiple consecutive images.

*Statistical Analysis*

Statistical analyses were performed using SPSS software version 27.0.1 (IBM Corp., Armonk, NY, USA). Data normality was assessed with the Shapiro-Wilk test. Descriptive statistics were presented as mean $\pm$ standard deviation (SD) for normally distributed data. Samples *t*-tests were used to compare normally distributed continuous variables between groups, while the Mann-Whitney U test was employed for non-normal continuous variables. Logistic regression analysis was performed to identify potential risk factors for RCTs. The predictive ability of each variable for RCTs was evaluated using receiver operating characteristic (ROC) curves. A two-sided *p*-value of less than 0.05 was considered statistically significant.

## Results

*Risk Factors for RCTs*

A total of 201 patients were included in this study, with 119 females and 82 males. The mean age was 59.30 years (standard deviation [SD] $\pm$ 8.87 years). RCTs were diagnosed by MRI in 72 patients, while the remaining 129 patients had no RCTs (N-RCTs). There were no significant differences in age or sex distribution between the two groups. Dominant side involvement was reported in 119 cases, while the non-dominant side was affected in 82 cases. Acromion types were categorized as follows: type I (n = 31 cases), type II (n = 146), and type III (n = 24). The mean AHD was 6.60 mm (SD $\pm$ 1.12 mm), and the mean CMS was 25.28 (SD $\pm$ 11.09). Independent samples *t*-tests revealed a significantly higher prevalence of RCTs on the dominant side ($p$ = 0.027). There were significant differences in the dis-

**Table 1. Univariate comparison of the parameters between RCT and nRCT groups.**

| Variable | | RCTs (n = 72) | N-RCTs (n = 129) | $t/\chi^2$-value | *p*-value |
|---|---|---|---|---|---|
| Age, years (Mean ± SD) | 59.30 ± 8.87 | 60.61 ± 10.16 | 58.57 ± 8.00 | 1.568 | 0.119 |
| Sex | | | | 0.035 | 0.851 |
| Male n (%) | 82 (40.8) | 30 (41.7) | 52 (40.3) | | |
| Female n (%) | 119 (59.2) | 42 (58.3) | 77 (59.7) | | |
| Side of dominance | | | | 4.883 | 0.027 |
| Yes | 119 (59.2) | 50 (69.4) | 69 (53.5) | | |
| No | 82 (40.8) | 22 (30.6) | 60 (46.5) | | |
| Duration of symptoms, months (Mean ± SD) | 12.19 ± 2.31 | 12.61 ± 2.58 | 11.96 ± 2.12 | 1.929 | 0.055 |
| Types of acromion | | | | 8.83 | 0.012 |
| Type I | 31 (15.4) | 5 (6.9) | 26 (20.2) | | |
| Type II | 146 (72.6) | 54 (75.0) | 92 (71.3) | | |
| Type III | 24 (11.9) | 13 (18.1) | 11 (8.5) | | |
| AHD, mm (Mean ± SD) | 6.60 ± 1.12 | 6.64 ± 1.18 | 6.57 ± 1.08 | 0.438 | 0.669 |
| CMS (Mean ± SD) | 25.28 ± 11.09 | 21.15 ± 9.41 | 27.59 ± 11.32 | 4.317 | <0.001 |

RCTs, rotator cuff tears; AHD, acromiohumeral distance; CMS, Constant-Murley Score; SD, standard deviation; N-RCTs, no RCTs.

**Table 2. Logistic regression analysis of risk factors for rotator cuff tears.**

| | OR (95% CI) | Wald Chi-Square | *p*-value | B-value | Standard Error (SE) |
|---|---|---|---|---|---|
| Side of dominance | 2.244 (1.165–4.326) | 5.868 | 0.016 | 0.809 | 0.334 |
| Types of acromion | | | | | |
| Type I | 1 | Reference | | 0 | 0 |
| Type II | 2.685 (0.909–7.927) | 3.287 | 0.074 | 0.987 | 0.553 |
| Type III | 6.106 (1.607–23.204) | 7.055 | 0.008 | 1.809 | 0.681 |
| CMS | 0.938 (0.908–0.969) | 14.178 | <0.001 | –0.064 | 0.017 |

OR, Odds Ratio; CI, Confidence Interval.

tribution of acromion types between the RCT and N-RCT groups ($p = 0.012$). The RCT group had a slightly higher mean AHD (6.64 mm, SD ± 1.18 mm) compared to the N-RCT group (6.57 mm, SD ± 1.08 mm), but this difference was not statistically significant ($p = 0.669$). Notably, the CMS score was significantly lower in the RCT group (21.15, SD ± 9.41) compared to the N-RCT group (27.59, SD ± 11.32) ($p < 0.001$) (Table 1).

### *Combining Dominant Side and Acromion Type in Predicting RCTs*

Logistic regression analysis revealed that dominant side involvement (Odds Ratio (OR) 2.244, $p < 0.05$) and type III acromion (OR 6.106, $p < 0.01$) were significant positive predictors of RCTs. Type II acromion did not show a significant association with RCTs (OR 2.685, $p = 0.074$). Similarly, type I acromion was not associated with a significant risk of RCTs. Conversely, a lower CMS score emerged as a significant negative predictor of RCTs (OR 0.938, $p < 0.001$). These findings are summarized in Table 2.

The combined parameter (CP) for predicting rotator cuff injury was formulated as:

$CP = OR_{Side} \times Side + OR_{Type} \times Type - OR_{CMS} \times CMS$

$CP = 2.244 \times Side + (2.685 \text{ or } 6.106) \times Type - 0.938 \times CMS$

(Side: 1 = right, 0 = left; Type: 1 = II or III, 0 = I)

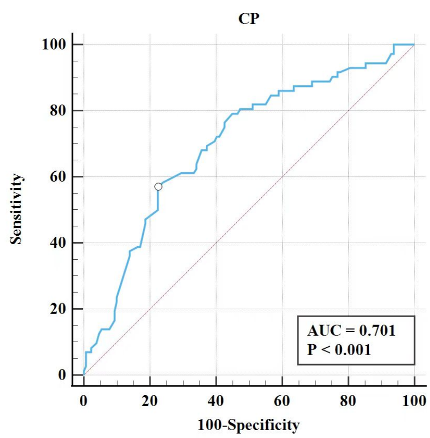


**Fig. 3. The receiver operating characteristic (ROC) curve depicts the diagnostic performance of the combined predictive model for RCTs.** Sensitivity and 100-Specificity are plotted on the y and x axes, respectively, expressed as percentages. The area under the curve (AUC) is 0.701 (Standard Error (SE) 0.039, 95% Confidence Interval (CI) 0.633–0.763). The Youden Index (J) is 0.345, corresponding to a critical value for the classification point (CP) of –13.831. This corresponds to a sensitivity of 56.94% and a specificity of 77.52%. Combined Parameter is 10.097 .

*ROC Analysis*

The results of the ROC analysis further substantiated the diagnostic efficacy of our predictive model (Fig. 3).

The ROC curve demonstrated a moderate ability to discriminate between patients with and without RCTs. The model, incorporating dominant side involvement, acromion type, and CMS, offers promise as a tool for identifying individuals at risk for RCTs. However, these findings require validation through further studies before clinical implementation.

## Discussion

Our investigation into rotator cuff tears yielded several compelling findings. One key observation challenged the conventional belief that decreased acromiohumeral distance is associated with a higher likelihood of RCTs due to mechanical impingement. In contrast, our data demonstrated an increased AHD in patients with RCTs. This finding may be attributed to supraspinatus tendon edema or hypertrophy following the tear, which aligns with a recent study by Hunter *et al*. [11], Michener *et al*. [18], and Joensen *et al*. [19], and challenges the traditional understanding of AHD's role in RCT development.

Our findings regarding acromial morphology align with prior research [20], demonstrating a higher prevalence of type II acromions in patients with rotator cuff tears. This further strengthens the established link between acromion morphology and RCTs, particularly highlighting the potential significance of the acromion angle as a contributing factor, as suggested by other studies [14, 21].

The study by Kalliopi Vrotsou *et al*. [22] showed that while the CMS may not be the definitive gold standard for overall shoulder assessment, its utility in evaluating subacromial lesions has been established. In this study, we employed the CMS as an independent variable to investigate its association with RCT diagnosis. The CMS provides a quantitative measure of a patient's shoulder function, making it a valuable component of our multivariable predictive model. Although not the gold standard, the CMS proved to be a crucial tool in our assessment of shoulder function. As shown in Table 2, our results demonstrate that lower CMS scores in patients with RCTs underscore the significant impact of rotator cuff pathology on both shoulder function and pain.

Our analysis revealed a significant association between the dominant side and the presence of RCTs. In this respect, 69.4% of tears occurred on the dominant side compared to 53.5% on the non-dominant side ($p$ = 0.027). This finding suggests that repetitive use and the resulting mechanical stress on the dominant shoulder may increase susceptibility to RCTs. Furthermore, our data align with previous research [23], indicating that dominant side usage emerges as a particularly significant factor in postmenopausal women, where a higher prevalence of full-thickness RCTs was observed on the dominant side. Future studies are warranted to elucidate the mechanisms underlying this dominance-related disparity and to develop targeted intervention strategies that address the specific needs of high-risk populations, such as postmenopausal women.

Although arthroscopy remains the definitive diagnostic and therapeutic modality for rotator cuff tears, our study primarily employed MRI due to its non-invasive nature, safety profile, widespread availability, and high diagnostic accuracy. This approach is particularly advantageous for patients who are not candidates for immediate surgical intervention. While arthroscopy offers unparalleled visualization and facilitates definitive repair, MRI's accessibility and safety render it a valuable diagnostic tool. Recognizing the unique strengths of arthroscopy, particularly in complex cases, future endeavors within this research program will involve a comparative analysis of both methods. This will allow for a more comprehensive evaluation of MRI's diagnostic efficacy and the potential for their complementary use in clinical practice.

Logistic regression analysis identified dominance side, acromion type, and CMS as independent risk factors for RCTs. Inspired by existing predictive models in orthopedics [24], we developed a novel equation to predict RCTs that incorporates these factors. While the $p$-value for the type II acromion category exceeded 0.05, its inclusion was warranted due to its large Odds Ratio (OR) and supporting evidence from prior research highlighting its significance [11]. The effectiveness of this predictive model was confirmed by ROC analysis. These findings suggest the model's potential clinical utility for rapid RCT screening using readily available X-rays and CMS, potentially improving healthcare efficiency and reducing patient burden [20].

Our findings suggest that routine screening for RCT risk factors could become an essential component of early intervention strategies. By identifying individuals at elevated risk based on specific demographic or physiological markers, clinicians can implement preventative measures. These may include targeted physical therapy programs, ergonomic adjustments in daily activities, and comprehensive patient education on injury prevention techniques. This proactive approach holds promise for reducing the overall incidence and severity of RCTs. Consequently, the need for invasive treatments could potentially decrease, leading to improved long-term patient outcomes.

The retrospective nature of our study introduces inherent limitations. Potential biases in data collection and the inability to control for all confounding variables are recognized limitations of this design. These limitations may affect the ability to definitively infer causality between the observed outcomes and the investigated variables. Additionally, the study's participant sample size restricts the statistical power of our analyses. This limitation is particularly relevant when considering the detection of significant effects or interactions within the data. As a result, type II errors may have occurred, where existing relationships between variables may not have been identified. The lack of statistical significance for the type II acromion in our multivariate analysis suggests two possibilities. It is highly conceivable that our study may not have comprehensively captured all relevant variables influencing RCT risk, or the sample size may have been insufficient to detect a significant effect for this specific acromion type. This finding highlights the complexity of factors influencing RCT development and underscores the need for a cautious interpretation of this particular result. Further research with larger and more diverse participant pools is warranted to confirm these observations.

To address the limitations inherent in the retrospective design, future research will employ a prospective study approach. This design allows for more controlled data collection, enabling direct observation of outcomes and potentially mitigating biases associated with retrospective analysis. Furthermore, enrolling a larger and more diverse participant population will significantly enhance the study's statistical power. This increased power will facilitate the detection of potentially significant effects and interactions within the data. Consequently, the generalizability of our findings to a broader patient population would be strengthened. With a more robust and diverse dataset, the next phase of this research program will focus on validating and refining our predictive model. This may involve incorporating additional relevant variables identified through future investigation. Additionally, employing more sophisticated statistical techniques could potentially enhance the model's predictive accuracy and overall clinical relevance.

## Conclusions

This study offers valuable insights into risk factors and predictive modeling for RCTs in patients presenting with shoulder pain. Our key findings identify reduced CMS, dominant side involvement, and type III acromion morphology as significant risk factors for RCT development. Notably, the study introduces a novel predictive model that incorporates these factors, offering a promising tool for early RCT identification. While demonstrating potential clinical utility, this model requires further validation through prospective studies. These findings contribute significantly to our understanding of RCTs, highlighting the importance of comprehensive risk assessment and innovative predictive approaches in clinical practice. The results pave the way for the development of enhanced screening strategies. Early identification of individuals at high risk for RCTs could potentially improve patient outcomes by facilitating timely and targeted interventions.

## Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Author Contributions

NX, FX and QG contributed to conception and design of study. NX, FX and DJ contributed to data acquisition, DJ and FX participated in measuring and collating the AHD data. NX, FX, and CL were involved in the analysis and interpretation of the data, as well as drafting the manuscript. All authors revised the manuscript critically for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

## Ethics Approval and Consent to Participate

Ethical approval and consent to participate in this study was approved by the Institutional Review Committee of the Ethics Committee of the Peking University International Hospital and conducted in accordance with the Declaration of Helsinki. Application for informed consent was waived for this study by the Institutional Review Committee of the Ethics Committee of the Peking University International Hospital. Ethics review number: 2023-KY-0001-02.

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## Conflict of Interest

The authors declare no conflict of interest.

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