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Original article

Age, trauma and the critical shoulder angle accurately predict supraspinatus tendon tears

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ABSTRACT

Background: The pathogenesis of full-thickness tears of the rotator cuff remains unclear. Apart from age and trauma, distinct scapular morphologies have been found to be associated with rotator cuff disease. The purpose of the present study was to evaluate whether a score formed using these established risk factors was able to predict the presence of a rotator cuff tear reliably.
Methods: We retrospectively assessed a consecutive series of patients with a minimal age of 40 years old, who had true antero-posterior (AP) radiographs of their shoulders, as well as a magnetic resonance (MR) gadolinium-arthrography, between January and December 2011. In all of these patients, the critical shoulder angle (CSA) was determined, and MR images were assessed for the presence of rotator cuff tears. Additionally, the patients' charts were reviewed to obtain details of symptom onset. Based on these factors, the so-called rotator cuff tear (RCT) score was calculated.
Results: Patients with full-thickness RCTs were significantly older and had significantly larger CSAs than patients with intact rotator cuffs. Multiple logistic regression, using trauma, age and CSA as independent variables, revealed areas under the curve (AUCs) for trauma of 0.55, for age of 0.65 and for CSA of 0.86. The combination of all three factors was the most powerful predictor, with an AUC of 0.92.
Conclusion: Age, trauma and the CSA can accurately predict the presence of a posterosuperior RCT.
Level of evidence: Level IV. Case series with no comparison groups.

1. Introduction

Rotator cuff tears (RCTs) are among the most frequent pathologies of the shoulder girdle [1]. Despite their considerable socioeconomic impact, there remains substantial controversy concerning their pathogenesis. Some tears are traumatic, but the vast majority are most likely degenerative and definitely age-related, as documented by prevalence data [2–5]. However, several risk factors, such as distinct scapular morphologies, seem to be able to accelerate the age-related degeneration [6–15].

Among the various radiographic parameters associated with degenerative RCTs, we recently identified the critical shoulder angle (CSA) as a powerful predictor of the occurrence of rotator cuff tears [10]. The purpose of the present study was to quantify the individual predictive power of age, trauma and the CSA for the presence of rotator cuff disease and to evaluate to what extent the combination of all three factors allowed for the anticipation of a patient's individual risk of experiencing a RCT.

2. Materials and methods

2.1. Patient selection

This study was conducted at the Balgrist University Hospital according to the medical-ethical guidelines of our institution, after obtaining informed consent from all of the individuals studied for retrospective data analysis. All patients older than 40 years old, who had a true antero-posterior (AP) radiograph of their shoulders, taken with the central X-ray beam parallel to the glenoid fossa, depicting a clear joint space and only minimal overhang between the anterior and posterior glenoid rim, plus magnetic resonance (MR) gadolinium-arthrography between January

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and December 2011, were included. A total of 599 patients with 607 shoulders met these inclusion criteria. The mean age of these 251 women and 348 men was 56.7 years (SD 10.4, range 40–88 years).

The patients' charts were retrospectively reviewed to obtain details of the symptoms leading to the imaging, and all of the shoulders were classified into one of three groups. In 398 shoulders (65.6%), complaints started spontaneously without any preceding trauma and were graded as "Trauma 0". In 159 shoulders (26.2%), classified as "Trauma 1", symptom onset was triggered by an accident (e.g., shoulder contusions or distortions), but no data quantifying the severity of the incidents were available. Finally, "Trauma 2" was attributed to 50 shoulders (8.2%) in which symptom onset was associated with a relevant documented accident (e.g., glenohumeral joint dislocation or fracture at the level of the shoulder girdle).

2.2. Radiological assessment

2.2.1. MR arthrography

Highly experienced, fellowship-trained musculoskeletal radiologists evaluated all of the MR arthrographic images. Imaging was performed with a 1.0-T unit (Siemens, Erlangen, Germany). The quality of the rotator cuff tendons was assessed on oblique coronal, oblique sagittal, and transverse T2-weighted and proton-density-weighted images, as well as on short tau inversion recovery sequences, according to established magnetic resonance imaging (MRI) criteria [16,17].

According to the radiological report, the integrity of the SSP tendon was classified into five categories. SSP 0 consisted of a normal tendon with a homogeneous, low-intensity signal on each image. SSP I consisted of tendinopathy with an increased intrasubstance signal but without pooling of contrast medium into the tendon substance. Bursal-sided and articular-sided partial tendon tears were graded as SSP II and III, respectively. A full-thickness tendon tear was graded as SSP IV. Additionally, the presence of full-thickness tears of the infraspinatus and subscapularis tendons was documented.

2.2.2. Conventional radiography

Two independent readers assessed the CSA on standardized, true antero-posterior radiographs. Both readers were blinded to the patients' MRI findings. All of the measurements were electronically obtained on radiographs displayed on a PACS workstation (Cerner Corp., Kansas City, MO, USA). Two lines, as previously reported, determined the CSA: the first line connected the superior and inferior osseous margins of the glenoid [10]; the second line was drawn from the inferior osseous margin of the glenoid to the most lateral border of the acromion (Fig. 1).

2.3. Statistical analysis

Statistical analysis was performed with the SPSS statistical software (SPSS Inc., Chicago, IL, USA). Descriptive analysis was performed to report means and standard deviations (SDs), as well as the ranges of the data. Intergroup comparison was achieved by means of statistical testing using the two-tailed unpaired *t*-test. Inter-rater reliability was assessed using the Bland-Altman method [18]. A multiple logistic regression, with trauma, age and CSA as independent variables, was performed to construct a predictive score for SSP tearing. Age and CSA were entered as continuous variables and trauma as a binary variable. The Hosmer-Lemeshow test was used to check the model fit. The regression coefficients were then rounded, and the two models were compared using the area under the receiver-operating characteristic (ROC) curve. Statistical significance was defined as $P < 0.05$.

Fig. 1. Assessment of the critical shoulder angle (CSA) on standardized true antero-posterior radiographs. The angle is formed by a line connecting the superior and inferior border of the glenoid fossa and a second line connecting the later with the most infero-lateral point of the acromion.

3. Results

The CSA demonstrated excellent inter-rater reliability, with minimal bias between reader A and reader B of 0.12° (limits of agreement of –2.2° to +2.7°; see Fig. 2).

MR arthrographic imaging revealed 134 cases of SSP 0 (22.1%), 130 of SSP I (21.4%), 22 of SPP II (3.6%), 85 of SSP III (14%), and 236 of SPP IV (38.9%). In addition to the lesions of the supraspinatus, there were 62 (10.2%) full-thickness tears of the infraspinatus and 51 (8.4%) of the subscapularis tendon. Most of these lesions were massive tears [19], with 36 (5.9%) tears involving the posterosuperior (supra- and infraspinatus) and 15 (2.5%) the anterosuperior (subscapularis and supraspinatus) rotator cuff. Involvement of all three tendons (subscapularis, supra- and infraspinatus) was encountered in 26 (4.3%) shoulders. There were no isolated lesions of the infraspinatus, but there were 10 (1.6%) of the subscapularis tendon.

SSP 0 patients were significantly younger ($P < 0.0001$), and SSP IV patients were significantly older ($P < 0.0001$), while there was no significant difference in age between SSP I and II patients, between I and III patients or between II and III patients (Table 1). SSP 0 shoulders had CSAs significantly smaller (31.6°; $P < 0.0001$) than those of SSP II (37.0°), SSP III (37.3°) and SSP IV (38.1°) shoulders.

These differences were even more pronounced in patients with a bland trauma history and were less evident in those with a Trauma 1 or 2 history (Fig. 3).

However, there were no significant differences in mean CSA between SSP 0 and I, nor between SSP II and III patients, between SSP II and IV patients or between SSP III and IV patients. Therefore, we simplified the SSP classification into a binary system (SSP_bin), which graded those shoulders with structurally intact tendons (SSP 0 and I) into SSP_bin 0 and those with partial or full-thickness tears (SSP II to IV) into SSP_bin 1.

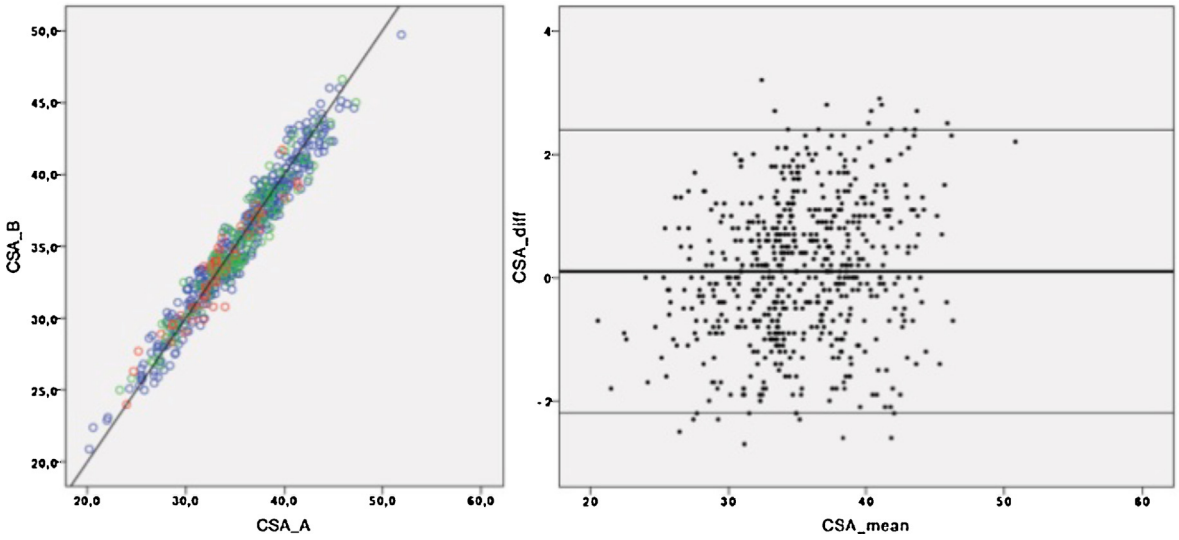

Fig. 2. Inter-rater reliability demonstrated with the Bland-Altman method. CSA_A/B: critical shoulder angle of rater A and B; o (blue) "Trauma 0″, o (green) "Trauma 1″ and o (red) "Trauma 2″ patients.

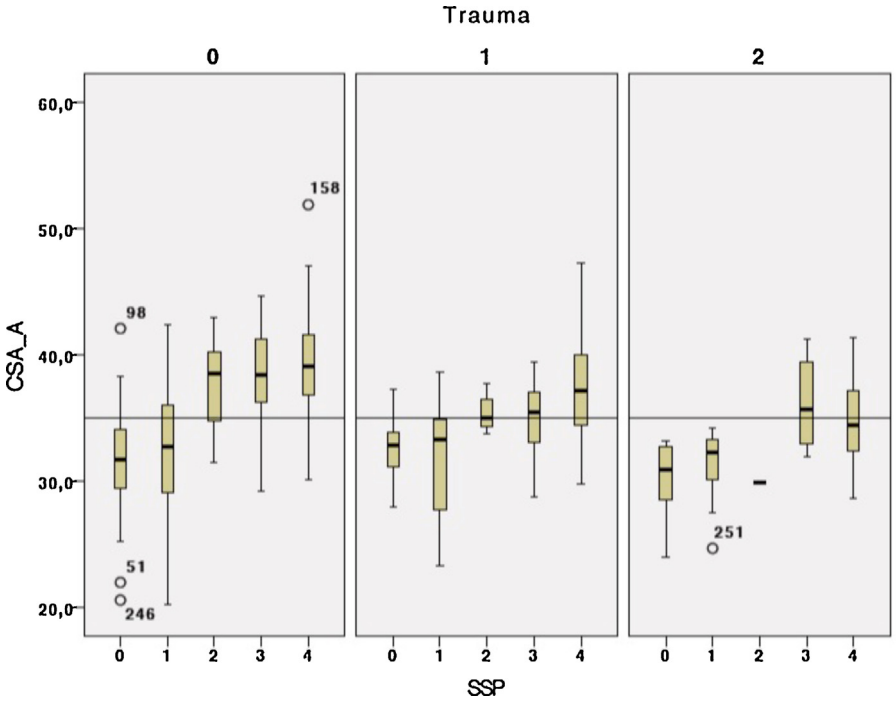

Fig. 3. Box plot comparing the integrity of the supraspinatus tendon (SSP 0 to 4) to the size of the critical shoulder angle (CSA). The data are further subdivided into patients with a negative (Trauma 0) or positive (Trauma 1 to 2) Trauma history.

The mean age of SSP_bin 0 ($n = 264$, 43.5%) was 53.6 years old (SD 9.9, range 40 to 88 years), and the mean age of SSP_bin 1 ($n = 343$, 56.5%) was 59.0 years old (SD 10.2, range 40 to 87 years). The mean CSA of SSP_bin 0 was 31.9° (SD 3.8, range 20.2 to 42.4°), while it was 37.8° (SD 3.8, range 28.7 to 51.9°) in SSP_bin 1 (Fig. 4). Both differences were statistically significant ($P < 0.0001$).

At 61.8 years old (SD 10.4, range 40 to 87), the mean age was even older in patients with massive rotator cuff tears ($P < 0.0001$). This subgroup also had the largest CSAs, with a mean of 38.4° (SD 4.3, range 29.8 to 51.9°; $P < 0.0001$).

Contrary to these findings, the CSA in shoulders with isolated full-thickness tears of the subscapularis ($n = 10$) was only 33.1° (SD 3.7, range 27.6 to 39.1). The mean age of these patients was 58.1 years old (SD 11.9, range 43 to 76 years), including 4 women and 6 men. Symptom onset was associated with a triggering trauma in 70% of these shoulders.

Multiple logistic regressions, with trauma, age and CSA as independent variables, revealed areas under the ROC curve (AUC) for trauma, age and CSA of 0.55 (standard error [SE], 0.02, range 0.50 to 0.60), 0.65 (SE 0.02, range 0.61 to 0.70) and 0.86 (SE 0.01, range 0.83 to 0.89), respectively. As expected, the predictive probability of the combination of all three factors (Pred prob age_CSA continuous/trauma categorical) was greatest, with an AUC of 0.92 (SE 0.01, range 0.89 to 0.94), indicating that it is the most valuable measurement for predicting an SSP tear (Fig. 5).

Because the differentiation between Trauma 1 and 2 did not substantially increase the predictive power of the model (Fig. 4), trauma was also simplified from a categorical to a binary variable

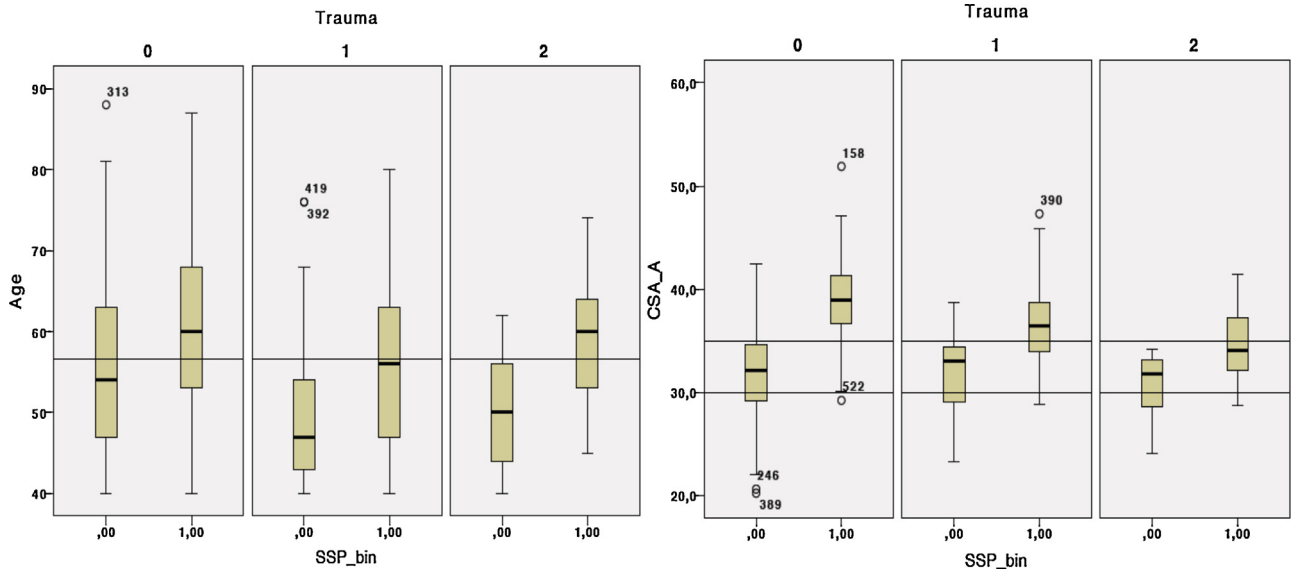

Fig. 4. Box plot comparing the integrity of the supraspinatus tendon (SSP_bin 0: intact tendon; SSP_bin 1: partial or full-thickness tear) to age (on the left) as well as the size of the critical shoulder angle (CSA; on the right). Again, data are additionally subdivided into patients with a negative (Trauma 0) or positive (Trauma 1 to 2) Trauma history.

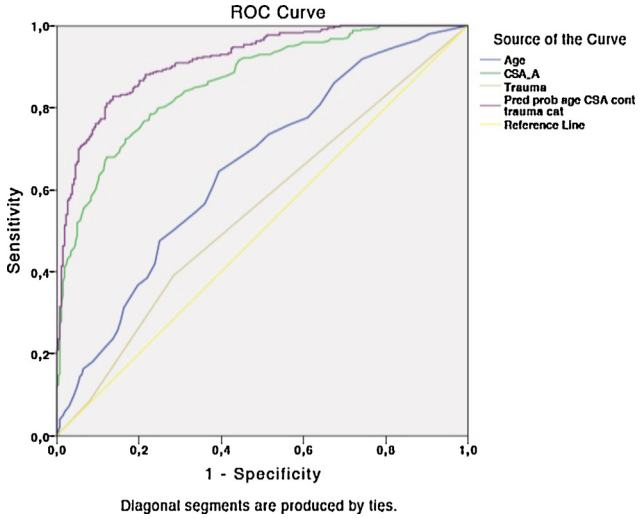

Fig. 5. Receiver-operating characteristic curves for Trauma (beige), age (blue), CSA (green) and the combination of all three factors (Pred prob age_CSA continuous/trauma categorical; violet). The reference line is indicated in yellow.

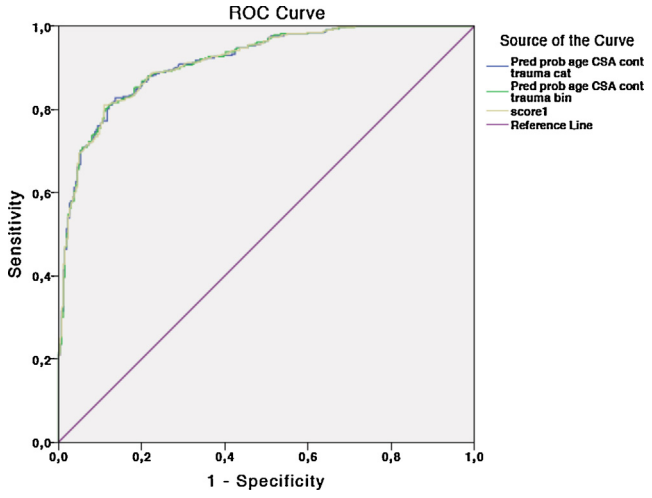

Fig. 6. Receiver-operating characteristic curves (ROCs) demonstrated excellent agreement of the three models (Pred prob age_CSA continuous/trauma categorical [blue]; Pred prob age_CSA continuous/trauma_bin [green], and RCT score [beige]). The reference line is indicated in violet.

Table 1
Synopsis of the overall dataset. Data are split according to age and the critical shoulder angle (CSA). The integrity of the supraspinatus tendon (SSP) is classified into five categories (0 to IV; with 0 indicating a completely normal tendon and IV a full-thickness tendon tear).

	Mean	SD	Min	Max	*n*
Age					
SSP 0	51.0	8.2	40	73	134
SSP I	56.4	10.8	40	88	130
SSP II	56.6	10.8	42	82	22
SSP III	55.6	10.1	40	82	85
SSP IV	60.5	9.9	40	87	236
CSA					
SSP 0	31.6	3.4	21	42	134
SSP I	32.2	4.1	20	42	130
SSP II	37.0	3.6	30	43	22
SSP III	37.3	3.7	29	45	85
SSP IV	38.1	4.0	29	52	236

(no trauma = trauma_bin 0 vs positive trauma history = trauma_bin 1).

Considering that the regression coefficient (B) of age (0.12; SE 0.02) was almost 5 times smaller than the regression coefficient of the CSA (0.54; SE 0.05), and 15 times smaller than the regression coefficient of trauma (1.78; SE 0.28), the following score was calculated.

$$RCTscore = (age - 50) + 5 \times (CSA - 35) + 15 \times trauma\_bin$$

Finally, ROC curve analysis revealed excellent agreement of the three models (Pred prob age_CSA continuous/trauma categorical, versus Pred prob age_CSA continuous/trauma_bin, vs RCT score), with an AUC of 0.915 (SE 0.011, range 0.89 to 0.94) (Fig. 6).

At a cut-off value of 10 points, the RCT score exhibited sensitivity of 0.84 and specificity of 0.81 in distinguishing patients with intact from those with torn SSP tendons. The predictive values of different levels of the RCT score are illustrated in Table 2.

Table 2
The predictive values of different levels of the rotator cuff tear (RCT) score are illustrated. SSP_bin 0 represents a structurally intact tendon while SSP_bin 1 indicates a partial or full-thickness tear of the supraspinatus tendon.

			RCT score					
			<0	0–10	10–20	20–30	>30	Total
SSP_bin	0	Count	162	52	38	7	5	264
		% within RCT score	87.1%	63.4%	38.8%	10.1%	2.9%	43.5%
SSP_bin	1	Count	24	30	60	62	167	343
		% within RCT score	12.9%	36.6%	61.2%	89.9%	97.1%	56.5%

4. Discussion

As expected, we found an increased probability of rotator cuff pathology in association with advanced age and trauma. Interestingly, there was no relevant increase in predictive power if the intensity of the triggering event could be quantified, which might have been due to the small number of Trauma 2 patients. In addition to these well-established risk factors, we were able to confirm the previously reported association of large CSAs with RCTs and to validate the CSA's excellent inter-rater reliability. Contrary to large angles, the risk of an SSP tear in shoulders with a CSA smaller than 30° was low, even in individuals subjected to relevant shoulder trauma. The integration of all three factors into one score accurately predicted the state of the SSP tendon in almost 90% of all 607 shoulders. However, the fact that the proposed scoring system did not address all of the individuals studied indicates that there are additional important risk factors for rotator cuff disease.

Balanced rotator cuff strength, compressing the humeral head into the glenoid concavity, is necessary to neutralize the upward-directed pull of the deltoid muscle [20,21].

Growing evidence suggests that increasing age, in combination with intrinsic and extrinsic factors, leads to progressive degeneration of the rotator cuff [4,8,13–15,22–24]. The weakened rotator cuff ultimately fails to withstand the superior pull of the deltoid muscle. The resulting cranial decentralization of the humeral head can result in secondary subacromial impingement and further tendon breakdown [25].

Theoretically, the larger the CSA is, the greater the workload of the rotator cuff must be to counterbalance the ascending force component of the deltoid [10,12]. This increased mechanical burden might accelerate the above-mentioned vicious cycle and therefore favour the development of RCTs. A single macrotrauma or multiple microtraumas could act similarly, selectively exacerbating the age-related degenerative process.

Conversely, the resulting force vector of the deltoid muscle is more centered on the glenoid surface if the CSA is small. This relationship seems to have a protective effect and might retard tendon degeneration, as suggested by the present data. However, although our study strengthened this hypothesis, further biomechanical studies are necessary to confirm a cause-effect relationship of the demonstrated associations.

In patients suffering from severe shoulder pain, it can be challenging to judge the integrity of the rotator cuff clinically. While unjustified MR arthrography burdens patients with an invasive and costly investigation, a missed RCT could unnecessarily delay correct treatment and prolong work incapacity. The proposed RCT score allows for the estimation of a patient's individual risk of an SSP tear even if his or her pain level impairs a conclusive clinical examination. If we consider a 60-year-old patient with atraumatic shoulder pain and a CSA of 40°, his or her RCT score would account for 35 points, indicating a probability of 97.1% that he or she suffers from an SSP tear (Table 2). However, if a patient's CSA, under otherwise comparable conditions, measures 30°, the RCT score accounts for –15 points, and the probability of a relevant SSP tear decreases to 12.9%. Under these conditions, conservative monitoring might be appropriate. Further investigations to judge the integrity of the rotator cuff would only be necessary if functional measurements (including non-steroidal inflammatory drugs, physiotherapy and occasionally cortisone shots) did not result in relevant clinical improvement within the first months of treatment or if the clinical examination became suggestive of rotator cuff disease [26–28].

There were limitations to this study. Our study group was certainly subject to selection bias, as only patients with symptoms sufficiently serious to warrant complementary investigation using MR arthrography were included. In 264 patients, MR arthrography revealed an intact rotator cuff. Despite the elevated pretest probability for an RCT, our scoring system accurately predicted an intact SSP tendon in 241 (91.3%) of these patients. In contrast, in 343 patients with SSP lesions, the RCT score only missed 41 patients (12%), 25 (7.3%) of whom had full-thickness tears. Another weakness was that the proposed scoring system did not include patients with isolated lesions of the subscapularis tendon, which seem to have a different pathogenesis.

5. Conclusion

This study confirms the previously reported association of the CSA with RCTs. In combination with established risk factors (age and trauma), a powerful score can be devised that accurately predicts the integrity of the posterosuperior rotator cuff. This score might therefore assist clinical practitioners in the assessment of patients suffering from shoulder pain and result in a more purposeful use of MR arthrographic imaging.

Disclosure of interest

Each author certifies that he or she has no commercial associations (eg., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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