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Clinical Research

High Acromial Slope and Low Acromiohumeral Distance Increase the Risk of Retear of the Supraspinatus Tendon After Repair

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Abstract

Background Retearing of the supraspinatus (SSP) tendon after repair is relatively common, but its cause is rarely clear. Although the role of acromion morphology and glenoid orientation in the pathogenesis of primary SSP tendon tears have frequently been analyzed, their association with the risk of rerupture of a repaired SSP tendon is poorly understood.

Questions/purposes (1) Is acromial morphology associated with the risk of retear after SSP tendon repair? (2) Is there an association between inclination and version of the glenoid and the odds for retear of the SSP tendon after repair? (3) Are there differences in outcome scores between patients who had intact cuff repairs and those who had retears?

Methods Between August 2012 and December 2015, we treated 92 patients for SSP tendon tears; all of these patients were considered for inclusion in the present study. We considered patients with complete tear of the SSP that was reconstructed with a double-row repair and a minimum follow-up of 2 years as potentially eligible. Based on these criteria, 28% (26 of 92) were excluded because they had a partial rupture and did not receive a double-row reconstruction. A further 9% (eight of 92) were excluded because of missing planes or slices (such as sagittal, axial, or frontal) on MRI, and another 3% (three of 92) were lost before the minimum study follow-up interval or had incomplete datasets, leaving 60% (55 of 92) for inclusion in the present analysis. All included patients had a minimum follow-up of 2 years; follow-up with MRI occurred at a mean duration of 2.3 ± 0.4 years postoperatively. All patients were asked to complete the Western Ontario Rotator Cuff Index and Oxford Shoulder Scores, and they underwent MRI of the operated-on shoulder. Preoperative true AP radiographs and MR images of the affected shoulders were retrospectively assessed by measuring the acromiohumeral interval, critical shoulder angle, acromial slope, acromial tilt, acromial index, lateral acromial angle, and glenoid version and inclination. The patients also underwent acromioplasty, in which the underface of the acromion was flattened. To rule out any change in the above parameters because of acromioplasty, these parameters were compared using preoperative and postoperative MR images and showed no difference. In addition, the tendon integrity and quality on postoperative MRI were analyzed independently of one another by the

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Independent institutional review board approval was obtained from the ethics committee of the University of Ulm (number 104/17).

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same two observers using the Sugaya and Castricini classifications, accounting for atrophy and fatty degeneration of the SSP muscle. To assess interobserver reliability, the two observers took measurements independently from each other. They were orthopaedic residents who completed a training session before taking the measurements. All measurements had excellent intrarater (Cronbach alpha 0.996 [95% confidence interval (CI) 0.99 to 1.00; p > 0.01) and interrater (interrater correlation coefficient 0.975 [95% CI 0.97 to 0.98]; p > 0.01) reliabilities. To answer the study's first question, SSP integrity on postoperative MRI was compared with acromial morphologic parameters measured on preoperative AP radiographs and MR images. To answer the second question, the postoperative integrity and quality of the SSP tendon were correlated with glenoid inclination and glenoid version. To answer our third question, we compared outcome scores between patients with intact SSP tendons and those with reruptured SSP tendons. To investigate any correlation among the acromial morphology, glenoid orientation, and postoperative outcomes, a binomial logarithmic regression analysis was performed. Receiver operating characteristic curves were used to determine cutoff points for the radiologic parameters that showed a correlation in the binomial regression analysis.

Results After controlling for potentially confounding variables such as acromioplasty or preoperative fatty infiltration as well as muscle atrophy, the only morphological parameters associated with a higher risk (adjusted odds ratio) of SSP tendon rerupture were the acromiohumeral interval (adjusted OR 0.9 [95% CI 0.9 to 0.99]; p < 0.01) and acromial slope (adjusted OR 1.4 [95% CI 1.1 to 1.8]; p < 0.01). The critical shoulder angle, acromial tilt, acromial index, and lateral acromial angle were not associated with the risk of rerupture. The cutoff values for acromial slope and acromiohumeral interval were 24.5° and 7.4 mm, respectively. Patients with an acromiohumeral interval smaller than 7.4 mm or an acromial slope greater than 24.5° had higher odds (acromiohumeral interval: OR 11 [95% CI 2 to 46]; p = 0.01 and acromial slope: OR 9 [95% CI 2 to 46]; p = 0.04) for rerupture of the SSP. No difference was found between patients with intact SSP tendons and those with reruptured SSP tendons in terms of glenoid inclination (6° ± 4° versus 6° ± 3°, mean difference 0.8° [-1° to 3°]; p < 0.48) and glenoid version (-2° ± 3° versus -3° ± 3°, mean difference 1° [-1° to 3°]; p < 0.30). No difference was found between the intact and reruptured SSP groups regarding clinical outcomes (Western Ontario Rotator Cuff Index: 98 ± 2 versus 97 ± 3, mean difference 0.73 [95% CI -0.30 to 0.31]; p = 0.96; Oxford Shoulder Score: 26 ± 13 versus 23 ± 10, mean difference 2.80 [95% CI -4.12 to 9.72]; p = 0.41).

Conclusion The preoperative acromiohumeral interval and acromial slope are associated with SSP tendon rerupture after repair. Conversely, the critical shoulder angle, acromial tilt, lateral acromial angle, and acromial index had no association with the postoperative outcome. Additionally, glenoid inclination and version were not associated with the rerupture rate after SSP tendon repair. A detailed analysis of the acromiohumeral interval and acromial slope is recommended in clinical practice in patients undergoing SSP tendon repair. Surgeons should consider measuring the acromiohumeral interval and acromial slope preoperatively when performing SSP repair, especially in the context of planned acromioplasties. Future studies should investigate the role of acromioplasty during SSP repair in patients with a pathologic acromial slope and acromiohumeral interval. In this context, it should be determined whether a more-radical acromioplasty could reduce the risk of rerupture of the SSP in these patients.

Level of Evidence Level III, therapeutic study.

Introduction

Despite great scientific interest, the pathogenesis of supraspinatus (SSP) reruptures after repair has not been determined [12, 25]. The acromion's morphology and glenoid orientation have been postulated as possible causes of SSP tendon reruptures after repair [23, 27]. Acromial morphology has been discussed as potentially relevant to the pathogenesis of primary SSP rupture because it is related to changes in the biomechanical forces acting on the SSP tendon and possible narrowing of the acromiohumeral interval [1, 3]. To better describe and quantify this relationship, some studies have developed radiographic parameters such as the critical shoulder angle, acromion inclination, acromion tilt, lateral acromion angle, and acromion index [24, 30, 31]. Additionally, glenoid orientation can alter the tensile forces acting on the repaired SSP tendon and thus affect the tendon's healing process [6, 17, 29]. Although several studies have evaluated the association of acromial morphology and glenoid orientation with the risk of suffering a first-time SSP tear [2, 8, 30], only two studies have focused on these factors' association with the risk of rerupture after SSP repair [1, 27]. The critical shoulder angle and glenoid index were recently found to increase the risk of rerupture of the SSP after repair, but this was not the case for glenoid inclination [13, 34]. Another study did not confirm these findings [7]. Thus, it remains unclear whether the preoperative acromion morphology impacts the risk of SSP tendon rerupture. Furthermore, the role of glenoid inclination and version on the postoperative risk of rerupture after SSP reconstruction has also seldomly been investigated. Although some studies have found an association with the risk of rerupture, no correlation has been established between the acromion and glenoid morphology and clinical results after repair [1, 23, 26]. Therefore, it would be interesting to know whether patients who suffered a rerupture also have worse clinical outcomes.

We therefore asked: (1) Is acromial morphology associated with the risk of retear after SSP tendon repair? (2) Is there an association between inclination and version of the glenoid and the odds for retear of the SSP tendon after repair? (3) Are there differences in outcome scores between patients who had intact cuff repairs and those who had retears?

Patients and Methods

Study Design and Setting

This retrospective study investigated the relationship of acromial morphology and glenoidal orientation with the risk of suffering a retear of the SSP 2 years after rotator cuff reconstruction. It was performed at one center in Germany and involved two observers (TC and ML, who were residents in orthopaedics).

Participants

Between August 2012 and December 2015, we treated 92 patients for SSP tendon tears who were considered for inclusion in the present study. We considered patients with complete tear of the SSP that was reconstructed with a double-row repair and those who had a minimum follow-up of 2 years as potentially eligible. Based on these criteria, 28% (26 of 92) were excluded because they had a partial rupture and did not receive a double-row reconstruction. A further 9% (eight of 92) were excluded because of missing MRI planes or slices (such as sagittal, axial, or frontal), and another 3% (three of 92) were lost before the minimum study follow-up interval or had incomplete datasets, leaving 60% (55 of 92) for inclusion in the present analysis. All included patients had a minimum follow-up of 2 years; follow-up occurred at a mean of 2.3 ± 0.4 years postoperatively.

Descriptive Data

A total of 51% (28 of 55) of the patients were women. The mean age was 66 ± 10 years (range 46 to 86 years). The right side was affected in 67% (37 of 55) of the patients, and the mean BMI was 29 ± 5 kg/m^2 (range 21 to 44 kg/m^2). Most (65% [36 of 55]) of the patients had American Society of Anesthesiologists Class II (Table 1).

Surgical Technique

Two experienced shoulder surgeons (TK and MS), who were not involved in the radiologic examinations, performed the arthroscopic procedures. The surgeons were senior surgeons who specialize in shoulder surgery and underwent surgical training for many years. The surgical indication was based on the patient's history and clinical examination, and the indication was confirmed with the use of MRI. Patients were initially treated with nonoperative therapy including physical therapy for at least 6 weeks. If the patient's condition did not respond to nonoperative therapy, they were advised to undergo surgical treatment. All patients had SSP ruptures with persistent symptoms after nonoperative treatment, and all patients were examined preoperatively with MRI. In all patients, the decision regarding surgery was made independently from the current study. All arthroscopies were performed with the patient under a brachial plexus block and general anesthesia. All surgeries were completed with the patient in the beach chair position, and an arm holding device (Trimano, Maquet) was used to hold their arms. Posterior, anterolateral, and lateral portals served as standard approaches. Diagnostic arthroscopy was performed. All SSP tears were reconstructed with a double-row technique. The surgeons were not involved in the clinical or radiologic follow-up examination. All relevant pathologic findings identified intraoperatively were treated. Tenodesis of the long head of the biceps (LHB) tendon was performed for instability of the LHB, superior labral tear from anterior to posterior (> 1°), or partial tears. All LHB tendon tenodeses were performed with one tenodesis technique using a Swivelock in the proximal part of the biceps groove. Mild acromioplasty consisting of flattening the underside of the acromion was performed in 76% (42 of 55) of the patients. Extended anterolateral shortening acromioplasties were not performed. The decision to perform acromioplasty was made intraoperatively when potentially relevant impingement with a corresponding rotator cuff lesion was identified. To exclude bias because of the acromioplasty, this procedure was included in the regression analysis and showed no association with the risk of retear of the rotator cuff. In addition, acromial morphology measurements were compared on preoperative and postoperative MR images and showed no difference.

Aftercare

After the surgical procedure, the operated-on arm was immobilized in an abduction pillow (Ultra Sling III) for 6 weeks. The patients were allowed to perform passive exercises for 6 weeks. Then, the pillow was discarded and no weightbearing active exercises were initiated. Strengthening exercises were recommended after 13 weeks.

Table 1. Demographic data and preoperative tendon quality of the investigated patients (n = 55)

Parameter	Value
Women, % (n)	51 (28)
Side involved, right, % (n)	67 (37)
Age in years, mean ± SD	66 ± 10
ASA classification, % (n)	
I	5 (3)
II	65 (36)
III	29 (16)
IV	0 (0)
BMI in kg/m^2, mean ± SD	29 ± 5
Tendon thickness grade, % (n)	
I	98 (54)
II	2 (1)
III	0 (0)
Footprint coverage grade, % (n)	
I	53 (29)
II	30 (17)
III	16 (9)
Signal intensity grade, % (n)	
I	87 (48)
II	13 (7)
III	0 (0)
Atrophy grade, % (n)	
I	78 (43)
II	20 (11)
III	2 (1)
Fatty infiltration grade, % (n)	
0	62 (45)
I	14 (8)
II	4 (2)
III	0 (0)

Interval-scaled variables were tested with a t-test. ASA = American Society of Anesthesiologists.

Clinical Assessment at Follow-up

All patients were clinically assessed at a minimum follow-up of 2 years by a single trainee in sports orthopaedics (DK). Patients were asked to complete two clinical shoulder scores: the Western Ontario Rotator Cuff Index [22] and the Oxford Shoulder Score [33].

Radiologic Examination at Follow-up

MRI was performed at the time of follow-up (2.3 ± 0.4 years) using a 1.5 Tesla MRI scanner (Magnetom TIM-Symphony). The patients were positioned in the supine position with the arm in neutral rotation by the side of their body. A dedicated standard shoulder coil was placed over the shoulder. Two blinded clinicians (TC and ML) analyzed MR images independently from one another; these MR images included measurements from preoperative and postoperative MRI. To obtain intrarater and interrater correlations, two orthopaedic surgeons (TK and MS) repeated all measurements; one of them, who was blinded to the first measurements, took repeated measurements after at least 6 weeks. The intrarater reliability was evaluated with a Pearson correlation coefficient for interval-scaled measurements. The interrater reliability was calculated using the intraclass correlation coefficient (ICC). Intrarater correlation coefficients are generally interpreted as follows: less than 0.5 is poor, between 0.5 and 0.75 is moderate, between 0.75 and 0.90 is good, and more than 0.90 is excellent. For all measurements, there were excellent intrarater (Cronbach alpha = 0.996 [95% confidence interval (CI) 0.994 to 0.998]; $p > 0.01$) and interrater (ICC = 0.975 [95% CI 0.970 to 0.979]; $p > 0.01$) reliabilities.

Measurements on Preoperative True AP Radiographs and MRI

As part of the preoperative plan, MRI was preoperatively performed on all shoulders in this study. MR images were obtained with a 1.5 Tesla MRI scanner without contrast. To assess acromial morphology and glenoid orientation, we measured the following parameters: critical shoulder angle (Fig. 1), acromiohumeral interval, acromial slope (Fig. 2), acromial tilt (Fig. 3), lateral acromial angle (Fig. 4), acromial index (Fig. 5), glenoidal version, and glenoidal inclination.

Acromiohumeral Interval

The acromiohumeral interval was defined as the shortest interval between the humeral head and acromion. It was measured on a true AP radiograph with the arm in neutral rotation. The acromiohumeral interval was determined using a perpendicular line between the proximal humeral head and the underface of the acromion. We measured the acromiohumeral interval because it is widely used in clinical practice and our department.

Glenoidal Version

Glenoid version was measured in the axial plane according to Friedman et al. [11]. First, the Friedman line, which connects the medial tip of the scapula to the center of the glenoid, was drawn. Then, a second line was traced between the anterior and posterior margins of the glenoid.

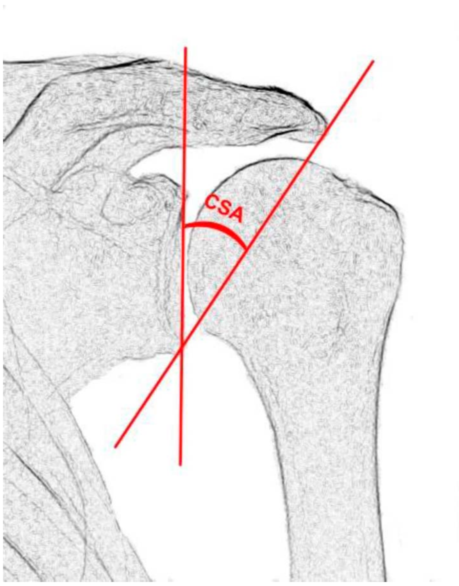

Fig. 1 This figure shows how the critical shoulder angle (CSA) was determined. The critical shoulder angle was defined as the angle between a line connecting the inferior glenoid border to the lateral acromion border and a line running from the inferior to the superior glenoid border.

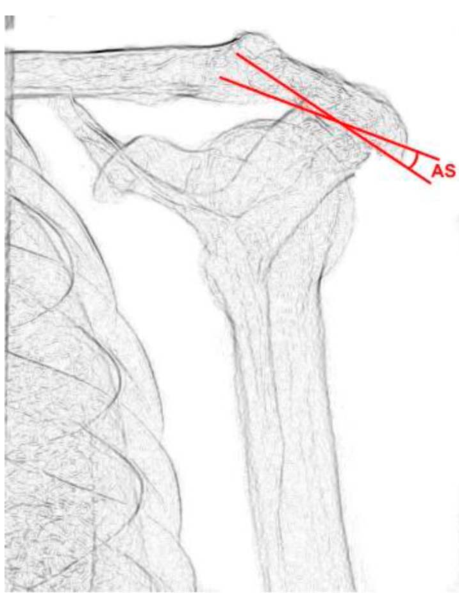

Fig. 2 The figure shows the measurement of acromial slope (AS). To measure acromial slope, the midpoint of the inferior acromion was established. A line was drawn between the most anterior edge of the acromion and the midpoint. A second line was drawn between the most posterior rim of the acromion and the midpoint of the inferior acromion. Acromial slope was defined as the angle between these two lines.

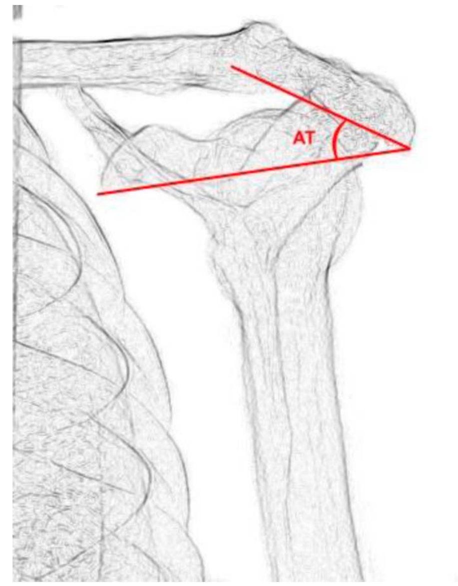

Fig. 3 The figure shows how acromial tilt (AT) was determined. Acromial tilt was defined as the angle between a line connecting the anterior and posterior margins of the acromion and a line extending from the posterior margin of the acromion to the distal end of the coracoid.

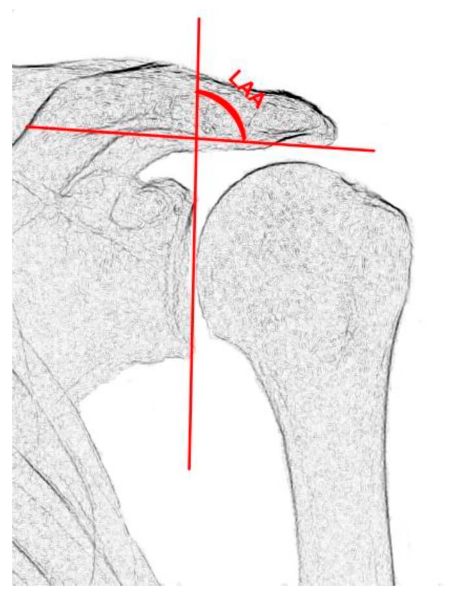

Fig. 4 The figure shows how the lateral acromial angle (LAA) was determined. First, a line was drawn between the superior and inferior rims of the glenoid. A second line, parallel and tangential to the inferior surface of the acromion, was then traced. The lateral acromial angle was defined as the angle between the two lines.

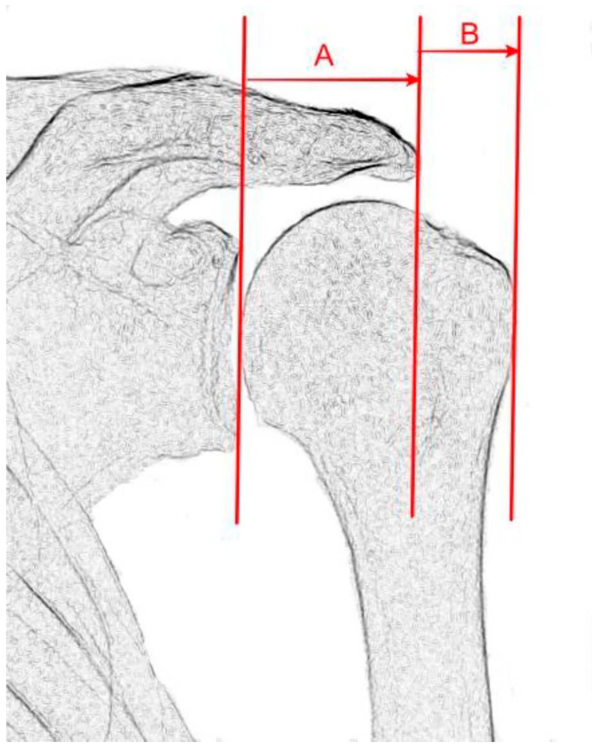

Fig. 5 The figure shows how the acromial index was determined. A line was drawn to connect the superior and inferior borders of the glenoid and defined as the glenoid plane. A second line, parallel to the glenoid plane, was drawn at the most lateral point of the acromion and defined as the acromion plane. Finally, a third line was drawn at the most lateral point of the humeral head and defined as the humeral head plane. The acromial index was calculated by dividing the distance between the glenoid and acromion planes (**A**) from that between the glenoid and humeral planes (**B**).

The angle between these two lines was defined as the glenoid version.

Glenoidal Inclination

Glenoid inclination was measured in the coronal plane using MRI according to Hughes et al. [17] and Maurer et al. [29]. Glenoid inclination was defined by determining the angle between a parallel, tangential line of the SSP fossa and a line connecting the superior and inferior margins of the glenoid.

Measurements on Postoperative MRI

To investigate the quality and morphologic integrity of the SSP tendon, the following radiologic parameters were determined using postoperative MRI performed 2.3 ± 0.4 years after surgery: Sugaya classification (Table 2) [10, 38]; SSP tendon integrity according to Castricini et al. [5], including signal intensity, footprint coverage, and tendon thickness (Table 3); fatty infiltration of the SSP muscle according to Goutallier et al. [14]; and SSP muscle atrophy according to Thomazeau et al. [36].

Table 2. Sugaya classification [10, 38]

Type 1	Sufficient thickness of the tendon, tendon continuity preserved, homogeneous low signal intensity
Type 2	Sufficient thickness of the tendon, with partial inhomogeneous areas of high intensity
Type 3	Tendon thickness reduced and tendon continuity maintained
Type 4	Low discontinuity of the tendon in the sagittal and coronal planes in one or two consecutive MR images
Type 5	Large discontinuity of the tendon on more than two consecutive MR images in the sagittal and coronal planes

Sugaya Classification

To assess the tendon's integrity, we applied the Sugaya classification (Table 2). In a recent study by Hasegawa et al. [16], the Sugaya classification showed good to excellent (kappa = 0.68 to 0.91) intrarater and good (kappa = 0.72) interrater reliability for the diagnosis of transmural rerupture of the SSP at 24 months after reconstruction. The Sugaya classification was dichotomized for analysis in the present study: Patients with Grades 1 to 3 were assigned to the intact group, and patients with Grades 4 and 5 were placed in the reruptured group.

Castricini Classification

To better investigate tendon quality after repair, we applied the Castricini classification [5] (Table 3). To better compare the differences, the individual subclasses were presented separately rather than collectively. Footprint coverage (k = 0.31), signal intensity (k = 0.35), and tendon thickness (k = 43) evaluated postoperatively using MRI showed fair-to-moderate interrater reliabilities in a recent study [16].

Fatty Infiltration of the SSP Muscle

We evaluated fatty infiltration according to Goutailler et al. [14]. A study on the reliability of assessing fatty infiltration

Table 3. Castricini classification [5]

Signal intensity	I	Higher signal intensity throughout the whole tendon thickness
	II	Focal increase of signal intensity
	III	Light and diffuse signal intensity
Footprint coverage	I	One-third of the greater tuberosity
	II	Two-thirds of the greater tuberosity
	III	100% of the greater tuberosity
Tendon thickness	I	< 50% of the tendon intact
	II	> 50% of the tendon intact
	III	Normal tendon thickness

with the Goutailler classification found good intrarater (ICC = 0.72) and interrater reliability (ICC = 0.68) [32].

Atrophy of the SSP Muscle

We graded SSP muscle atrophy according to Thomazeau et al.'s method [36]. A study analyzing SSP muscle atrophy during the first year after reconstruction showed moderate agreement for interrater and intrarater reliability values using MRI [28].

Primary and Secondary Study Outcomes

Our primary study goal was to investigate the association between acromion morphology and SSP rerupture rates 2 years after repair. All preoperative MR images were used by two blinded observers (TC and ML) to measure the acromiohumeral interval, critical shoulder angle, acromial slope, acromial tilt, lateral acromial angle, and acromial index in all patients. Furthermore, both observers analyzed the tendon's integrity and quality on postoperative MRI based on the Sugaya classification, Castricini classification, muscle atrophy, and fatty degeneration. Postoperative evaluation of tendon integrity was based on the measurements of acromion morphology obtained on preoperative true AP radiographs and MRI. Our second primary study outcome was to analyze the association of glenoid inclination and version with radiologic outcomes 2 years after repair. Thus, on all preoperative MR images, the glenoid inclination and glenoid version were measured in all patients by two blinded observers (ML and TK). Both observers analyzed the tendon's integrity and quality on postoperative MRI using the Sugaya and Castricini classifications. Tendon integrity was then correlated to the measured glenoid inclination and version. Our secondary study objective was to analyze the clinical postoperative outcome in patients with rerupture of the SSP compared with patients with an intact SSP. To answer our third research question, therefore, postoperative outcomes at follow-up were compared between patients with reruptured SSPs and those with intact SSPs.

Ethical Approval

Independent institutional review board approval was obtained from the ethics committee of the University of Ulm (number 104/17).

Statistical Analysis

The sample size was calculated based on a binomial logarithmic regression analysis, assuming a 95% CI, a 0.15 effect size, and including seven predictors, resulting in a sample size of at least 55 patients, with a power of 0.88. The statistical analysis was performed using SPSS (version 24, IBM Corp). All collected data were secured in a computerized database. Descriptive statistics were used. To assess the correlation among the acromial morphology, glenoid version, and glenoid inclination, as well as with clinical and radiologic postoperative outcomes, a logarithmic binomial regression analysis was first performed. Receiver operating characteristic curves were used to calculate cutoff points for the radiologic parameters that showed a correlation in the binomial regression analysis. Moreover, sensitivity, specificity, odds ratios, and area under the curve were calculated. The area under the curve reflects the discriminatory accuracy of a diagnostic test and represents the mean sensitivity for all specificities; it ranges from 0 to 1. The area under the curve was classified as follows [15]: failed (0.5 to 0.6), poor (0.6 to 0.7), fair (0.7 to 0.8), good (0.8 to 0.9), and excellent (0.9 to 1.0). Furthermore, patients were divided into two groups depending on the presence of an SSP rerupture on postoperative MRI, according to the Sugaya classification (Group 1: Sugaya Grades 1 to 3 and Group 2: Sugaya Grades 4 and 5). Acromial morphology, glenoid inclination, and glenoid version measured on preoperative MRI were then compared between the two groups. When comparing measurement methods between the intact and reruptured SSP groups, a one-sample t-test was used for interval-scaled parameters. The Wilcoxon signed-rank test was used as t-test ordinal-scaled dimensions. Differences were considered significant for p values < 0.05.

Results

Acromial Morphology and Retear Risk

Only the acromiohumeral interval (adjusted OR 0.9 [95% CI 0.9 to 0.99; p < 0.01) and acromial slope (adjusted OR 1.4 [95% CI 1.1 to 1.8]; p < 0.01) were associated with the risk of SSP rerupture after repair (Table 4). According to the explorative logarithmic regression analysis, patients with a reruptured SSP had a lower acromiohumeral distance and greater acromial slope (Table 5). A cutoff of 7.4 mm was obtained for the acromiohumeral interval and 24.5° for the acromial slope (Fig. 6). Patients with an acromiohumeral interval less than 7.4 mm and patients with an acromial slope greater than 24.5° had a 10.6-fold and 8.9-fold risk of rerupture of the reconstructed SSP tendon, respectively. For acromial slope and the acromiohumeral interval in relation to the probability of SSP reconstruction failure, we found a sensitivity of 77 (95% CI 46 to 95) and 85 (95% CI 54 to 98), specificity of 76 (95% CI 60 to 88) and 62 (95% CI 46 to 76), an OR of 11 (95% CI 2 to 46) and 9 (95% CI 1.8 to 46), and area under the curve of 0.82 (95% CI 0.6 to 0.9) and 0.73 (95% CI 0.6 to 0.9), respectively (Table 6). There were no differences in clinical outcomes between those above and below the cutoffs for acromiohumeral interval (Table 7) and acromial slope (Table 8), but radiologic parameters were worse in patients with a greater acromial slope and lower acromiohumeral interval. No difference was found between the preoperative and postoperative acromiohumeral interval (78.2 ± 21.6 mm versus 77.4 ± 24.8 mm, mean difference -0.83 [95% CI -2.3 to 4.0]; p = 0.66) and acromial slope (24.5 ± 4.0 versus 25.0 ± 5.3, mean difference 0.58 [95% CI 0.36 to 1.52]; p = 0.22).

Table 4. Logarithmic multivariate regression analysis of the likelihood of suffering a rerupture of the SSP tendon

Variable	Adjusted OR (95% CI)	p value
Acromial slope	1.4 (1.1 to 1.8)	< 0.01
Acromiohumeral distance	0.9 (0.9 to 0.99)	< 0.01
Acromial tilt	1.0 (0.8 to 1.3)	0.71
Acromial index	3.7 (0.0 to 1.7)	0.87
Lateral acromial angle	1.2 (0.9 to 1.5)	0.21
Glenoidal inclination	0.6 (0.4 to 1.1)	0.08
Glenoidal version	1.0 (0.8 to 1.4)	0.65

The model achieved statistical significance in four steps (p < 0.001). Concomitant subscapularis reconstruction, tenodesis of the long head of the biceps tendon, lateral clavicula resection, and acromioplasty were included in the regression analysis and showed no significant association and are not listed in the table. The model correctly classified 84% of instances and explained 54% (Nagelkerke $r^2 = 0.535$) of the variance in cuff retear because of acromial slope and acromiohumeral interval. SSP = supraspinatus tendon.

Glenoid Morphology and Retear Risk

There was no difference between patients with intact SSP tendons and those with reruptured SSP tendons in terms of glenoid inclination (6° ± 4° versus 6° ± 3°, mean difference 0.8° [-1° to 3°]; p < 0.48) and glenoid version (-2° ± 3° versus -3° ± 3°, mean difference 1° [-1° to 3°]; p < 0.30) (Table 9).

Clinical Outcome

No difference in clinical outcomes was found between patients with intact SSPs and those with reruptured SSPs (Western Ontario Rotator Cuff Index: 98 ± 2 versus 97 ± 3, mean difference 0.73 [95% CI -0.30 to 0.31); p = 0.96; Oxford Shoulder Score: 26 ± 13 versus 23 ± 10, mean difference 2.80 [95% CI -4.12 to 9.72]; p = 0.41) (Table 10).

Discussion

Acromion morphology and glenoid orientation may be associated with the risk of SSP tendon ruptures [8, 18, 37]. However, it is unclear whether these morphologic characteristics are associated with the rerupture risk after SSP tendon repair. This study showed that only the acromiohumeral interval and acromial slope influenced the SSP tendon rerupture risk at 2 years after repair. Moreover, in this study, acromial and glenoidal morphology were not associated with clinical and radiologic outcome. In light of the results of the present analysis, shoulder surgeons should consider that patients with a preoperative acromiohumeral interval smaller than 7.4 mm or an acromial slope greater than 24.5° may be at a higher risk of SSP tendon rerupture.

Table 5. Comparison between patients with an intact SSP and those with a reruptured SSP regarding preoperative acromial morphology and glenoid orientation

Variable	Sugaya 1 to 3	Sugaya 4 and 5	Mean difference (95% CI)	p value
AHI in mm	83 ± 20	61 ± 16	22.1 (10.7 to 33.5)	< 0.01
CSA in °	34 ± 4	33 ± 4	1.6 (-1.1 to 4.5)	0.24
AS in °	24 ± 3	27 ± 3	3.6 (1.2 to 6.1)	< 0.01
AT in °	38 ± 4	40 ± 4	2.0 (-4.2 to 2.0)	0.48
LAA in °	80 ± 5	80 ± 5	0.1 (-4.0 to 3.7)	0.95
AI, quotient	0.6 ± 0.1	0.6 ± 0.1	0.01 (-0.05 to 0.02)	0.61

Data are presented as the mean ± SD. SSP = supraspinatus tendon; AHI = acromiohumeral interval; CSA = critical shoulder angle; AS = acromial slope; AT = acromial tilt; LAA = lateral acromial angle; AI = acromial index.

Limitations

First, in most instances, the analyzed patients underwent mild acromioplasty. Because the probability of suffering a retear of the SSP tendon was evaluated using parameters before acromioplasty, the measured change in acromion morphology because of acromioplasty might have biased the results. To exclude this bias, the acromiohumeral interval and acromial slope measured preoperatively were compared with the values measured postoperatively. No difference was found, so this potential bias could be excluded. Second, a limited number of patients were analyzed. To avoid bias, the included patients were subjected to a strict preselection process. Only patients with SSP tendon rupture treated with a double-row reconstruction technique were included. In our opinion, this criterion was important because if patients who had undergone a different reconstructive technique for the SSP had been included, this could have affected the postoperative outcome and possibly biased the results. The few studies conducted to date have generally not examined a substantially large number of patients. Furthermore, the sample size calculation in this study showed sufficient power and indicates the study had sufficient validity. Therefore, this limitation may not have influenced the conclusions of our study. Third, we performed no comparison with a control group. Selection bias is possible because we included only patients with a symptomatic rotator cuff tear, and we excluded asymptomatic patients because such patients might have other morphologic characteristics. However, the aim of our study was not to determine the cause of the primary SSP tendon rupture before reconstruction; rather, this study aimed to investigate the risk factors for SSP tendon rerupture after reconstruction. A comparison with an asymptomatic group of patients who had intact SSP tendons and who did not undergo reconstruction would not have provided additional information.

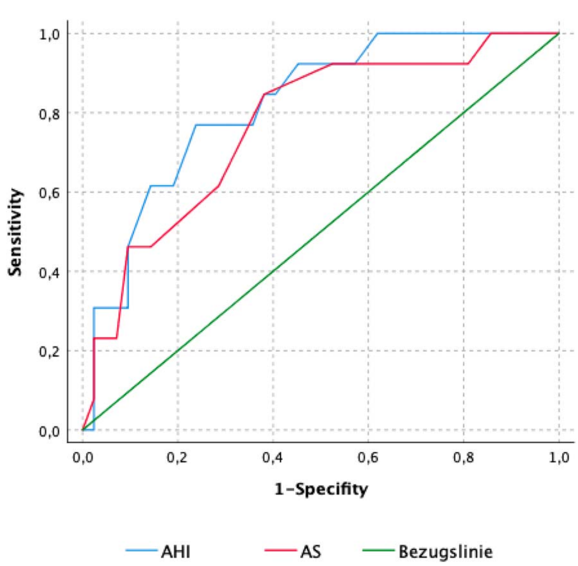

Fig. 6 The figure represents the receiver operating characteristic curve of the acromiohumeral interval and acromial slope. The coordinates on the curve determined the cutoff values for identifying a retear: 7.4 mm for the acromiohumeral interval and 24.5° for acromial slope. A color image accompanies the online version of this article.

Fourth, because the preoperative MRI examinations were performed before the start of this study, standardization of imaging techniques was not possible a priori. This is a limitation of the present study because the preoperative and postoperative MRIs do not have identical slice orientations, which could have affected the measurement accuracy. This would particularly be true if we had performed the same measurements using preoperative and postoperative images; in this study, however, this was not the case. Acromion morphology, glenoid version, and glenoid inclination were measured on preoperative images, whereas postoperative images were used to determine the SSP tendon's quality and integrity. Therefore, this limitation is unlikely to have played an important role. Fifth, MRI was performed with a 1.5 Tesla rather than a 3.0 Tesla MRI machine. A 3.0 Tesla MRI machine would have further improved the accuracy of the measurements because of its higher

Table 6. Sensitivity, specificity, likelihood ratio, OR, and AUC of acromial slope and acromiohumeral distance

Variable	Acromiohumeral distance (95% CI)	Acromial slope (95% CI)
Sensitivity, %	77 (46 to 95)	85 (54 to 98)
Specificity, %	76 (60 to 88)	62 (46 to 76)
OR	11 (2 to 46)	9 (1.8 to 46)
AUC	0.82 (0.6 to 0.9)	0.73 (0.6 to 0.9)

AUC = area under the curve.

resolution. However, we do not have a 3.0 Tesla MRI in our department; this reflects the situation in most clinics and therefore does not seem to be a major limitation.

Sixth, residents performed the measurements. Because of their inexperience, they may have produced imprecise results. To avoid this, both observers underwent training before the measurements, during which several trial measurements with corresponding repetitions occurred after verbal and written instruction. The observers started real measurements only when the intrarater reliabilities were good. Therefore, this limitation probably did not have a major effect on data validity. Seventh, the current study had short-term follow-up. This could have influenced the validity of the results of our study because ruptures of the SSP tendon can occur even a long time after healing. This limitation might have influenced the relevance of the present study. However, compared with the few studies that have been performed on this topic so far, the present study has one of the longest follow-up periods. Thus, we think this limitation does not affect the results of the present study. Nevertheless, studies with a longer follow-up period are needed to verify whether our results remain consistent. Moreover, most of the included patients had no or very low fatty infiltration of the SSP muscle. Because rotator cuff ruptures are often chronic with preexisting or even advanced fatty infiltration, this may limit the power of the study. The aim of the present study was to investigate the morphology of the glenohumeral joint and the orientation of the glenoid in relation to the rate of rerupture rather than all possible risk factors for rerupture. The inclusion of patients with advanced atrophy or fatty infiltration may have biased the assessment of the influence of acromial morphology and glenoid orientation, so we do not consider this limitation detracts from our findings. Finally, in the present study, one of the two observers (as opposed to both) repeated the measurements; however, both observers were trained a priori to make the measurements. Both observers started taking study-related measurements only after their intrarater reliabilities had reached good values. Therefore, measurement repetition by the second observer would likely have had no effect with the data.

Acromial Morphology and Retear Risk

We found that of the acromial morphologic measures analyzed, only acromial slope and acromiohumeral distance were associated with a higher risk of recurrence 2 years after SSP repair. The critical shoulder angle was not a predictive factor for postoperative outcome. These findings are important because they allow shoulder surgeons to identify possible preoperative predictive factors that may or may not be associated with a higher risk of SSP retear. Surgeons are advised to determine the acromiohumeral distance and acromial slope preoperatively and consider them during surgery. Regarding the acromiohumeral interval, one study [9] observed that a low acromiohumeral interval is associated with rotator cuff retear [9]. Another study reported that a narrower acromiohumeral interval is related to rotator cuff rerupture after repair [39]. Chalmers et al. [7] found there was no association between acromial slope and the rerupture rate after repair. One study found

Table 7. Clinical and radiologic outcomes depending on the AHI cutoff

Variable	AHI ≤ 7.4 mm	AHI > 7.4 mm	p value
WORC, mean ± SD	97 ± 2.6	97 ± 2.2	0.56
Oxford, mean ± SD	29 ± 13	22 ± 11	0.06
Tendon thickness grade, mean ± SD	1.5 ± 0.7	2.0 ± 0.7	0.02
Footprint coverage grade, mean ± SD	2.0 ± 0.9	3.0 ± 0.5	0.001
Tendon quality grade, mean ± SD	1.5 ± 0.8	3.0 ± 0.7	0.002
Fatty infiltration grade, mean ± SD	0.5 ± 0.8	0.0 ± 0.4	0.001
Muscle atrophy grade, mean ± SD	1.5 ± 0.5	1.0 ± 0.3	0.005

AHI = acromiohumeral interval; WORC = Western Ontario Rotator Cuff Index.

Table 8. Clinical and radiologic outcomes depending on the AS cutoff

Variable	AS ≤ 24.5°	AS > 24.5°	p value
WORC, mean ± SD	97 ± 2.3	97 ± 2.6	0.84
Oxford, mean ± SD	25 ± 14	24± 11	0.77
Tendon thickness grade, mean ± SD	2.0 ± 0.7	2.0 ± 0.8	0.06
Footprint coverage grade, mean ± SD	3.0 ± 0.6	3.0 ± 0.9	0.01
Tendon quality grade, mean ± SD	3.0 ± 0.7	2.0 ± 0.9	0.03
Fatty infiltration grade, mean ± SD	0.0 ± 0.3	0.0 ± 0.8	0.02
Muscle atrophy grade, man ± SD	1.0 ± 0.4	1.0 ± 0.5	0.31

AS = acromial slope; WORC = Western Ontario Rotator Cuff Index,

that a higher critical shoulder angle is associated with a higher risk of full-thickness retears of the rotator cuff at shorter follow-up intervals. Another study reported that a critical shoulder angle more than 38° is associated with a fourfold risk of an SSP rerupture in the short-term follow-up period after repair [34]. The results of our study confirm the findings of the abovementioned studies about the acromiohumeral interval, but not those concerning the acromial slope and critical shoulder angle. However, most of the mentioned studies had a different setting than ours and therefore cannot be compared without restriction. Thus, only the study by Scheiderer et al. [34] can be used for comparison. Our results concerning the critical shoulder angle do not agree with those of Scheiderer et al. [34]. This was surprising because our study and that one were very similar in terms of design and approach. Because of longer follow-up and consideration of more morphologic parameters, the conclusions of our study have a stronger meaning. Future studies addressing the association between acromial morphology, including the critical shoulder angle, should investigate whether modifying the acromial morphology during surgery can improve postoperative outcomes.

Glenoid Morphology and Retear Risk

We found that glenoid orientation in terms of inclination and version was not associated with radiologic outcomes after SSP repair. Glenoid orientation could impact the forces acting on the reconstructed tendon [6, 35]. However, according to our results, surgeons do not need to measure glenoid morphology preoperatively because it does not appear to play a predictive role in rerupture of the SSP. A study compared repaired SSP tendons with the intact contralateral side and found less inclination of the repaired shoulders [4]. Scheiderer et al. [34] found that glenoid inclination did not correlate with the risk of SSP rerupture after repair. Kandemir et al. [21] compared glenoid version in 12 cadaveric shoulders with rotator cuff tears against 12 shoulders without rotator cuff tears and found no difference between the two groups. Another study found that glenoid retroversion is associated with anterior rotator cuff tear and that glenoid anteversion is associated with posterior rotator cuff tear [35]. Tokgoz et al. [37] found that patients with SSP tendon rupture had lower glenoid version. The results of our study regarding glenoid inclination confirm the work of Scheiderer et al. [34]; however, the postoperative follow-up period in our study was longer. On the other hand, we cannot compare our study and the aforementioned studies regarding glenoid version. This is because the aim of our study—to investigate the impact of glenoid version on postoperative clinical and radiologic outcomes after rotator cuff repair—has not been investigated. Overall, considering the different study design, the results of our study about glenoid version partially reflect the findings of Kandemir et al. [21]; no association between glenoid version and SSP tendon primary rupture was found in either study. Future studies should investigate whether glenoid orientation plays a role in the rupture rates of other rotator cuff tendons, such as the infraspinatus or subscapularis tendon.

Table 9. Comparison between patients with an intact SSP and those with a reruptured SSP regarding preoperative acromial morphology and glenoid orientation

Variable	Sugaya Groups 1 to 3	Sugaya Groups 4 and 5	Mean difference (95% CI)	p value
GV in °	-2 ± 3	-3 ± 3	1.0 (-1.5 to 3.1)	0.30
GI in °	6 ± 4	6 ± 3	0.8 (-1.0 to 3.2)	0.48

SSP = supraspinatus tendon; GV = glenoidal version; GI = glenoidal inclination.

Table 10. Postoperative clinical outcomes depending on SSP integrity

Variable	Sugaya Groups 1 to 3	Sugaya Groups 4 and 5	Mean difference (95% CI)	p value
WORC in points	98 ± 2	97 ± 3	0.7 (-0.3 to 0.3)	0.96
Oxford in points	26 ± 13	23 ± 10	2.8 (-4.1 to 9.7)	0.41

Data are presented as the mean ± SD. SSP = supraspinatus tendon; WORC = Western Ontario Rotator Cuff Index.

Clinical Outcome Depending on Retear of the SSP

We found no difference in clinical outcome between patients with intact and reruptured SSP tendons and no association with preoperative glenoid morphology and orientation. These results are important because they demonstrate that worse radiological outcomes do not always have clinical consequences. Additionally, these findings may help surgeons make a careful decision when the SSP tendon ruptures again after reconstruction. Other studies [23, 26, 28, 35] reported no association of clinical outcome, preoperative morphology of the acromion and glenoid, and rerupture rate of the SSP tendon. A study found that a larger critical shoulder angle correlated with worse postoperative American Shoulder and Elbow Surgeons scores [13]. In terms of clinical outcome, the present study confirmed the findings of previous studies [23, 26, 27, 34]. This was to be expected, because several studies that examined only the rerupture rate without considering acromial morphology and glenoid orientation have shown that despite a rerupture of the rotator cuff, patients are often satisfied after reconstruction [19, 20]. The present study showed that even consideration of the above-mentioned morphologic parameters does not change this fact. Future studies should clarify whether there is no relationship of acromial morphology and glenoid orientation with clinical outcome, even after a longer follow-up period.

Conclusion

We found that acromiohumeral distance and acromial slope are associated with the risk of retear of the SSP tendon after repair. In addition, we observed no association of glenoid inclination and glenoid version with the rate of retear of the SSP tendon after repair. Finally, there was no difference in clinical outcome between patients with intact SSP tendons and those with reruptured SSP tendons. The results of our study suggest that preoperative consideration of the acromiohumeral distance and acromial slope may help surgeons to identify patients who are at a greater risk of rerupturing the SSP tendon. This could help to optimize specific surgical approaches and postoperative care of these patients. Studies with a longer follow-up period and larger number of patients should be performed to clarify whether the associations observed in our study persist after a longer follow-up period. In addition, studies might investigate whether more-radical acromioplasty can reduce the risk of rerupture of the SSP in these patients.

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