Large Critical Shoulder Angle Has Higher Risk of Tendon Retear After Arthroscopic Rotator Cuff Repair

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Background: The critical shoulder angle (CSA) is the angle created between the superior and inferior bone margins of the glenoid and the most lateral border of the acromion. A few studies recently investigated the relation between CSA and functional outcomes after rotator cuff repair. However, there is a lack of research investigating the effect of CSA on postoperative tendon integrity after rotator cuff repair.

Purpose: To assess the effects of the CSA on postoperative tendon integrity after rotator cuff repair.

Study Design: Cohort study; Level of evidence, 3.

Methods: All patients who underwent rotator cuff repair for full-thickness supraspinatus tears by 1 senior surgeon between January 2010 and January 2014 were included in this study. All patients had standardized anteroposterior shoulder radiographs the day before surgery. CSA and acromial index (AI) were measured. AI was derived by measuring the distance from the glenoid plane to the lateral border of the acromion and dividing it by the distance from the glenoid plane to the lateral aspect of the humeral head. Functional scores—including American Shoulder and Elbow Surgeons shoulder evaluation form, modified University of California at Los Angeles score, Constant-Murley score, and visual analog scale for pain—were used to evaluate shoulder function at a minimum follow-up of 2 years. Meanwhile, magnetic resonance imaging examinations were performed to evaluate rotator cuff integrity according to the Sugaya method and the signal/noise quotient (SNQ) of the rotator cuff tendon.

Results: A total of 90 patients were included in this study: 42 patients with a single-row repair and 48 with a double-row repair. There was a significant positive correlation between CSA or AI and tendon SNQ. On the basis of CSA, the patients were divided into 2 groups: large CSA (>38°) and control (CSA ≤38°). At final follow-up, the large CSA group and the control CSA group demonstrated no significant differences in American Shoulder and Elbow Surgeons, University of California at Los Angeles, Constant, and visual analog scale scores. Postoperative magnetic resonance imaging revealed that the large CSA group had 9 cases of retear, with a significantly higher retear rate than the control group (15% vs 0%, P = .03). Furthermore, the tendon SNQ of the large CSA group was significantly greater than that of the control group.

Conclusion: CSA did not appear to influence postoperative functional outcomes, while those in the large CSA group had poor tendon integrity after rotator cuff repair. These findings indicate that a large CSA is associated with an increased risk of rotator cuff tendon retear after repair.

Keywords: MRI; rotator cuff; CSA; retear; tendon integrity

Rotator cuff tears (RCTs) are common among older patients and can have a negative effect on daily life as a result of a loss of motion and strength.[10,40] Intrinsic anatomic factors, such as the critical shoulder angle (CSA) and acromial index (AI), have recently emerged as important factors of interest in RCTs. CSA is the angle created between the superior and inferior bone margins of the glenoid and most lateral border of the acromion. AI is derived by measuring the distance from the glenoid plane to the lateral border of the acromion and dividing it by the distance from the glenoid plane to the lateral aspect of the humeral head. CSA combines the measurements of the inclination of the glenoid and the lateral extension of the acromion, and AI describes the lateral extension of the acromion.[22] Many studies indicate that larger CSAs and AIs are associated with a full-thickness RCT.[17,29,31,34] Moor et al[29] reported that patients with degenerative RCTs demonstrated significantly higher AI and larger CSA than did patients with intact rotator

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One or more of the authors has declared the following potential conflict of interest or source of funding: This work was supported by the National Natural Science Foundation of China (81401812).

The American Journal of Sports Medicine
1–9
DOI: 10.1177/0363546518767634

cuffs. Spiegl et al[34] also demonstrated that a larger CSA was associated with RCTs. Although these studies demonstrated an association between CSA and RCT, there is growing interest in investigating the relationship of CSA and RCT repair outcomes postoperatively.

In addition, retears of repaired rotator cuffs have been observed on magnetic resonance imaging (MRI) after successful repair,[6] which arouses a lot of concern. An ideal rotator cuff repair would have perfect tendon healing at the repair site, which could guarantee high initial fixation strength and clinical efficiency.[8] Clinically, MRI is a widely applied noninvasive tool to evaluate the integrity, fatty degeneration, and muscle atrophy of the repaired rotator cuff tendon.[16,23,25] The presence of structural integrity on MRI proved to be a good criterion for assessment of rotator cuff tendon integrity after repair.[33] To date, there is a lack of research investigating the effect of CSA on tendon retear after rotator cuff repair with MRI.

Therefore, the aim of the present study was to assess and compare the clinical function and MRI appearance of the repaired tendon between a large CSA group and a low CSA group at 2 years postoperatively. Given that larger CSA or AI is associated with degenerative RCTs preoperatively, it was hypothesized that the large CSA group would have poor tendon integrity and a higher retear rate as compared with the low CSA group postoperatively. Second, it was hypothesized that higher AI was also associated with poor tendon integrity.

METHODS

Participants

The study was approved by the Health Sciences Institutional Review Board of our hospital, and written consent was obtained from all participants. All patients who underwent arthroscopic repair of the supraspinatus tendon between January 2010 and January 2014 were invited to participate. The inclusion criteria were (1) full-thickness RCT and (2) no history of reinjury of the rotator cuff.

Participants were excluded if they had any of the following: (1) massive RCT, (2) acromioclavicular arthritis that required distal clavicle resection, (3) advanced glenohumeral osteoarthritis, or (4) a revision procedure. Then, the patients were divided into 2 groups on the basis of the CSA: control (CSA $\leq 38°$) and large CSA ($>38°$).[12] CSA is the angle created between the superior and inferior bone margins of the glenoid and the most lateral border of the acromion. Patient selection details are illustrated in Figure 1. At final follow-up, 90 patients with RCT repair were included: 60 patients in the large CSA group and 30 in the control group.

Surgical Technique

All operations were performed by 1 senior surgeon with the patient in a lateral position. A posterior viewing portal and an anterior working portal were used to assess the glenohumeral joint. After diagnostic arthroscopy was performed

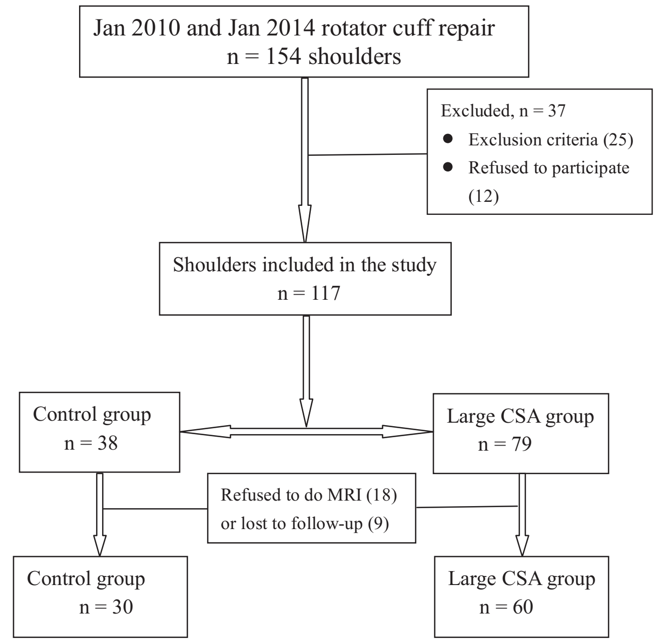

Figure 1. Patient selection flowchart involvement in the study. CSA, critical shoulder angle; MRI, magnetic resonance imaging.

through the posterior portal, the arthroscope was inserted through the posterior portal to the subacromial space, and a lateral portal was created. After subacromial bursectomy was performed through this portal, the pattern of the RCT in the subacromial space was observed. The tear size was measured in the anterior-posterior dimension with a probe introduced through the posterior portal while being viewed from the lateral portal. For rotator cuff repair, standard arthroscopic rotator cuff repair was performed with a single- or double-row method (Figure 2). Regarding how to choose the single-row or suture bridge technique, the single-row technique was mainly performed in the beginning of the study period, whereas the double-row technique was gradually used, as it was considered to be useful in improving the healing potential of the repaired tendon.

Postoperative Rehabilitation

All patients followed a standard postoperative rehabilitation program. From the day of operation, passive exercises were performed, including pendulum, forward flexion, and external rotation exercises. Active-assisted exercises were started at 6 weeks postoperatively, and muscle-strengthening exercises were introduced gradually. Recreational activity was allowed at 3 months postoperatively.

Radiographic Assessment

All patients had conventional anterior-posterior shoulder radiographs the day before surgery. CSA and AI were measured according to previous investigations, with anterior-posterior shoulder radiographs.[11,22] CSA was formed with

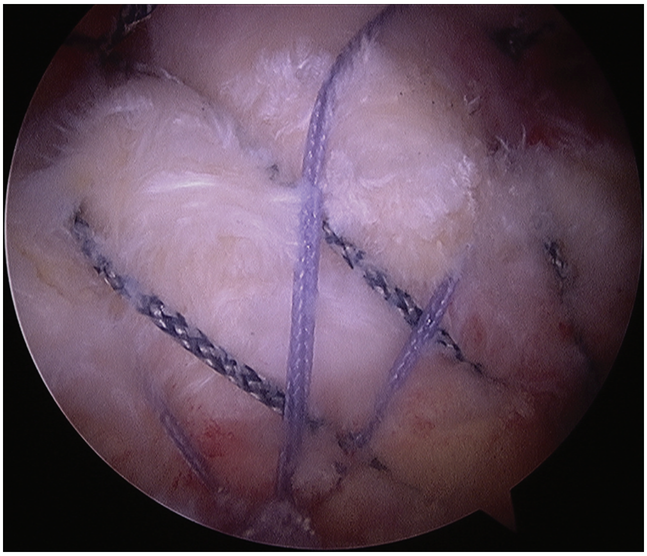

Figure 2. Repair configuration after arthroscopic rotator cuff repair with a double-row (suture bridge) technique.

a line connecting the superior and inferior bone margins of the glenoid and a line drawn from the inferior bony margin of the glenoid to the most lateral border of the acromion. AI was measured with the following equation: AI = GA/GH, with GA being the distance from the glenoid plane to the lateral border of the acromion and GH being the distance from the glenoid plane to the lateral aspect of the humeral head (Figure 3).

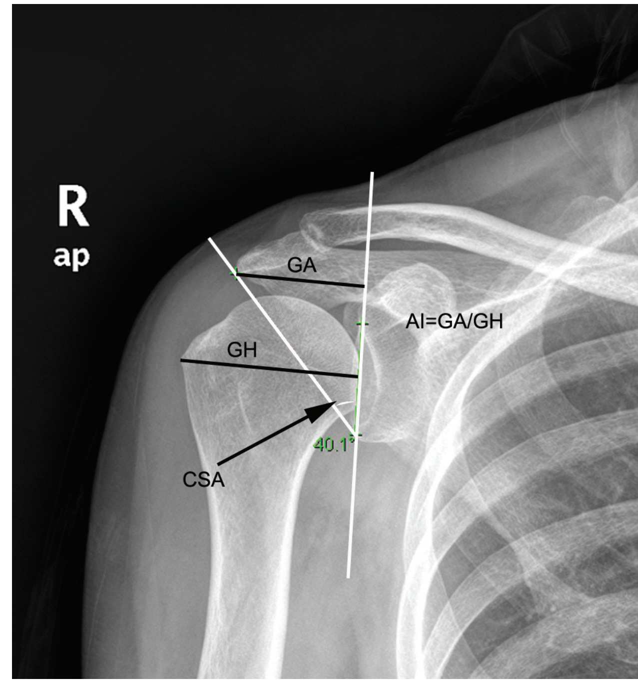

Figure 3. The critical shoulder angle (CSA) is formed by a line connecting the inferior with the superior border of the glenoid fossa and another line connecting the inferior border of the glenoid with the most inferolateral point of the acromion. The acromial index (AI) is the distance from the glenoid plane to the lateral border of the acromion (GA) divided by the distance from the glenoid plane to the most lateral aspect of the humeral head (GH).

Clinical Function Assessments

The Constant-Murley score, American Shoulder and Elbow Surgeons (ASES) shoulder evaluation form, and modified University of California at Los Angeles (UCLA) score were used for the functional assessment. Subjective pain was ranked by the patients on a visual analog scale for pain (VAS), in which 0 indicated that the functional condition of the shoulder had worsened after surgery and 10 indicated that the recovery perfectly met or even exceeded expectations. During postoperative assessments, the strength of abduction was tested with the patient in the seated position and the arm abducted to 90°, as suggested by the guidelines for use of the Constant-Murley score.

MRI Scan and Image Analysis

Imaging was performed with a 3.0-T MRI scanner (MAGNETOM Verio, A Tim System; Siemens), with the patient in a relaxed extended position. All participants had at least 1 hour of rest before the MRI scan. The sequences mainly included oblique coronal short time inversion recovery, oblique coronal T1-weighted, oblique sagittal T2-weighted, and oblique axial proton density–fat saturation images. All these images were imported into Siemens Software Packages (NUMARIS/4, SyngoMR B17) for evaluation of the shoulder by a single clinician without knowledge of patient details.

The MRI evaluation focused on 2 measurements based on oblique coronal short time inversion recovery images. First, postoperative cuff integrity was classified into 5 categories according to a previous method[37]: type I, appearance of sufficient thickness on repaired cuff as compared with normal cuff, with homogeneously low intensity on each image; type II, sufficient thickness versus normal cuff associated with partial high-intensity area; type III, insufficient thickness with less than half the thickness as the normal cuff but without discontinuity, suggesting a partial-thickness delaminated tear; type IV, presence of a minor discontinuity in only 1 or 2 slices on oblique coronal and sagittal images, suggesting a small full-thickness tear; type V, presence of a major discontinuity observed in >2 slices on oblique coronal and sagittal images, suggesting a medium or large full-thickness tear. For type IV and V tendon integrity, the repaired tendon was considered retear.

Second, the signal intensity was calculated at the rotator cuff tendon site as well as the background site approximately 2 cm anterior to the shoulder) with a circle region of interest (Figure 4). To quantify the normalized signal intensity of the tendon, the signal/noise quotient (SNQ) of the rotator cuff tendon site was calculated with the following equation: SNQ = signal of tendon / signal of background. Three consecutive slice images containing screws were chosen to measure the SNQ, and these SNQ values

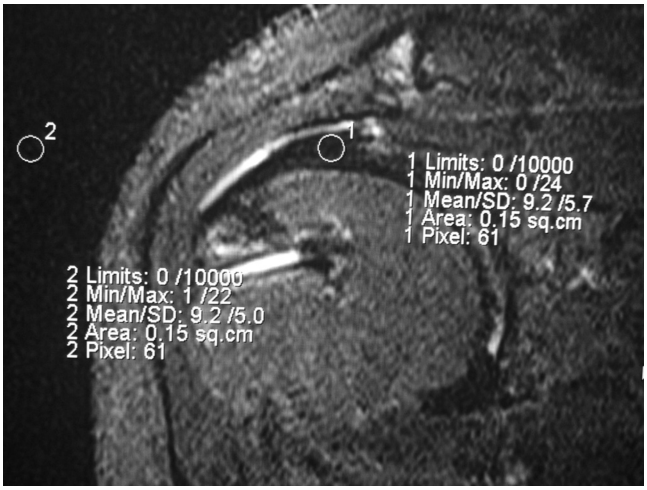

Figure 4. The signal intensity was calculated at the (1) rotator cuff tendon site as well as (2) the background site approximately 2 cm anterior to the shoulder.

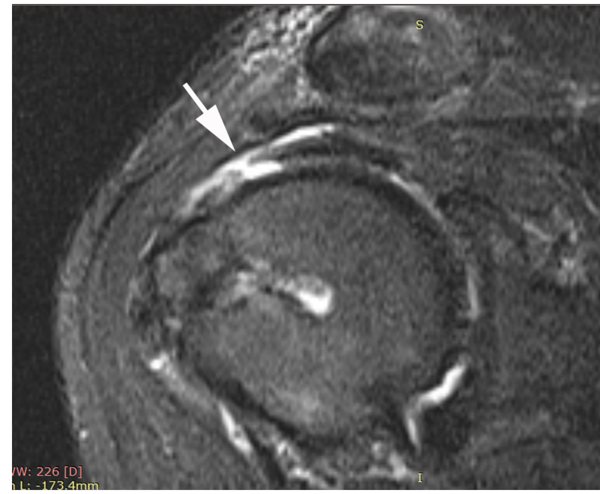

Figure 5. The retear pattern on postoperative oblique coronal magnetic resonance imaging in shoulders with recurrent tear (white arrow) after rotator cuff repair.

were then averaged to obtain the mean SNQ value for each case. For cases with type IV or V tendon integrity, SNQ was not measured.

Statistical Analysis

Data analysis was performed with Stata software (v 10.0; Stata Corp), and the data were reported as mean and SD for description. Spearman correlation coefficients were calculated between CSA (or AI) and other factors (functional scores, VAS, strength, tendon SNQ). Comparisons between groups were made with the Student *t* test or 2-sample Wilcoxon rank sum test for continuous variables. Chi-square test or Fisher exact test was used to compare the categorical variables. Moreover, a post hoc power analysis was performed to evaluate the sample size. If a difference of at least 10 was detected in the functional score (ASES or Constant score) between groups, it was considered a clinically significant difference in the functional scores.[22] Given the SD of the functional score (ASES or Constant score) in the data, the sample sizes of the control group and the large CSA group had a power of 80% when the level of significance was set at .05. To quantify the proportion of the variance from the CSA and tendon SNQ measurements, the intraclass correlation coefficient (ICC) was assessed by examining intra- and interobserver reliabilities. The ICC was interpreted as follows: poor, <0.4; marginal, ≥ 0.4 to ≤ 0.75; good, >0.75. A 2-tailed P value $<.05$ was set as statistical significant.

RESULTS

All these patients were followed up at a mean 35 ± 12 months. At final follow-up, functional assessment scores were as follows: ASES, 88 ± 10; UCLA, 31 ± 3; and Constant, 75 ± 8. The mean VAS was 1.4 ± 1.4; the mean CSA was 42.7° ± 5.7°; and the mean AI was 0.77 ± 0.09.

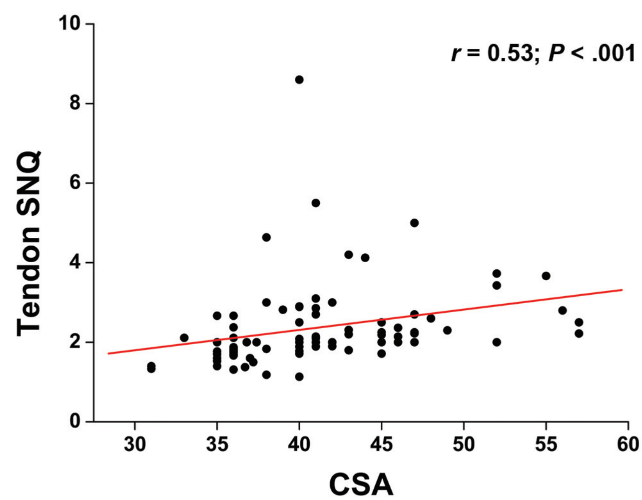

Figure 6. Correlation between the critical shoulder angle (CSA) and the tendon signal/noise quotient (SNQ) value. There was a significant positive association between the CSA and tendon SNQ value.

Forty-two patients had a single-row repair, and 48 had a double-row repair. Furthermore, a retear pattern (Figure 5) was observed in 9 cases, including 6 with a single-row repair and 3 with a double-row repair.

There was no significant association between CSA and functional factors for this cohort: ASES (r = 0.01, P = .91), UCLA (r = 0.02, P = .87), Constant score (r = –0.16, P = .13), VAS (r = –0.10, P = .37), and strength (r = –0.01, P = .90). A significant positive correlation was found between CSA and tendon SNQ (r = 0.53, P < .001) (Figure 6). Similarly, this cohort demonstrated no significant association between AI and functional factors (ASES, UCLA, Constant score, VAS, strength), although a significant

TABLE 1
Participant Characteristics Based on CSA[a]

	Large CSA (n = 60)	Control (n = 30)	*P* Value
Age, y	55.0 ± 7.3	55.8 ± 6.3	.626
Body mass index, kg/m^2	23.1 ± 2.7	23.2 ± 3.4	.895
Sex			
Male	13	6	.855
Female	47	24	
Side			
Left	25	12	.880
Right	35	18	
Tear size, cm	2.9 ± 1.0	2.4 ± 0.8	.052
Repair technique			.990
SR	28	14	
DR	32	16	
Follow-up, mo	33 ± 12 (24-73)	37 ± 13 (24-78)	.130
CSA, deg	45 ± 5	36 ± 2	<.001
AI	0.82 ± 0.06	0.68 ± 0.05	<.001
ASES	88.0 ± 9.7	87.3 ± 11.0	.772
UCLA	30.9 ± 2.9	31.0 ± 3.2	.921
Constant	74.3 ± 8	77.0 ± 7.0	.124
VAS	1.4 ± 1.4	1.5 ± 1.4	.833
Strength, lb	8.1 ± 3.6	7.6 ± 3.1	.507

[a]Values are presented as mean ± SD or n. AI, acromial index; ASES, American Shoulder and Elbow Surgeons; CSA, critical shoulder angle; DR, double row; SR, single row; UCLA, University of California at Los Angeles; VAS, visual analog scale.

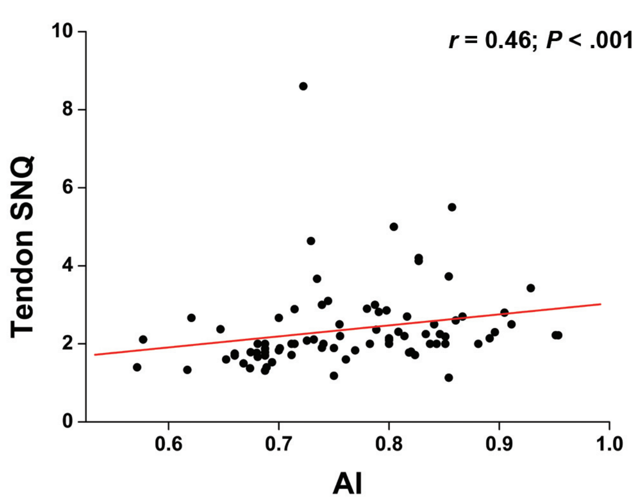

Figure 7. Correlation between the acromial index (AI) and the tendon signal/noise quotient (SNQ) value. There was a significant positive association between the CSA and tendon SNQ value.

positive correlation was found between AI and tendon SNQ ($r = 0.46$, $P < .001$) (Figure 7).

Based on CSA, the large CSA group comprised 60 patients and the control group, 30 patients. The participants' characteristics are shown in Table 1. The groups revealed no significant differences between them regarding age, BMI, and follow-up time. The control group had 14 single-row repairs and 16 double-row repairs. In the large CSA group, 28 patients underwent a single-row repair and 32, a double-row repair. There was no significant difference of repair technique between groups ($P > .05$). The mean tear size of the large CSA group was slightly greater than that of the control group but without significant difference (2.9 ± 1.0 vs 2.4 ± 0.8 cm, $P = .052$). Radiograph assessment showed that the large CSA group had a greater CSA and AI than the control CSA group ($P < .001$).

At final follow-up, there was no significant difference in ASES (88.0 ± 9.7 vs 87.3 ± 11.0, $P = .772$), UCLA (30.9 ± 2.9 vs 31.0 ± 3.2, $P = .921$), Constant score (74.3 ± 8 vs 77.0 ± 7.0, $P = .123$), and VAS (1.4 ± 1.4 vs 1.5 ± 1.4, $P = .833$) between the large CSA group and the control group, respectively. Moreover, no significant difference of abduction strength existed between the large CSA group (8.1 ± 3.6 lb) and the control group (7.6 ± 3.1 lb, $P = .507$).

Postoperative MRI revealed the tendon integrity of both groups: large CSA group—type I (n = 14), type II (n = 22), type III (n = 15), type IV (n = 6), and type V (n = 3); control group—type I (n = 9), type II (n = 14), type III (n = 7), type IV (n = 0), and type V (n = 0). Additionally, postoperative MRI revealed that the large CSA group had a significantly higher retear rate (15%) than the control group (0%, $P = .03$) (Figure 8). Furthermore, the ICC indexes of intra- and interobserver reliability were 0.93 and 0.91 for CSA and 0.81 and 0.77 for tendon SNQ, respectively. The postoperative tendon SNQ of the large CSA group (2.6 ± 1.2) was significantly greater than that of the control group (1.9 ± 0.7, $P = .003$) (Figure 9).

When the patients were divided according to AI—control (AI ≤0.7) and large AI (>0.7)[22]—there were 23 patients in the control group and 67 in the large AI group. Similarly, no significant differences in ASES, UCLA,

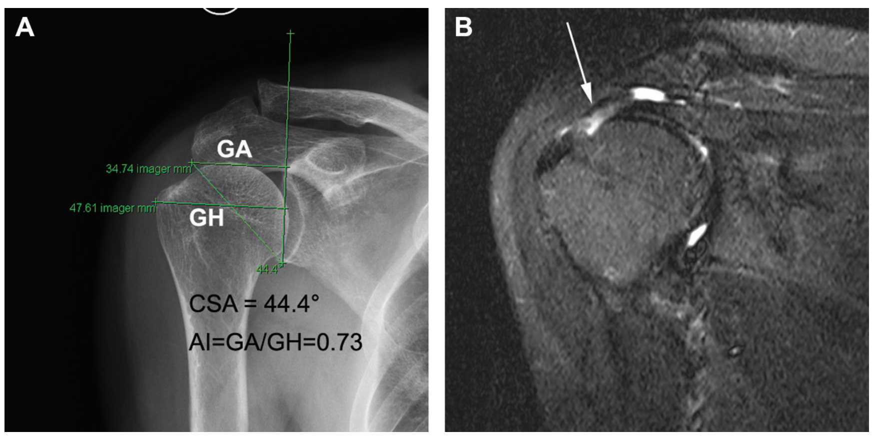

Figure 8. A 43-year-old woman with a large critical shoulder angle (CSA) had a tendon retear: (A) radiograph and (B) magnetic resonance image. White arrow indicates retear tendon. (See Figure 3 for angle definitions.)

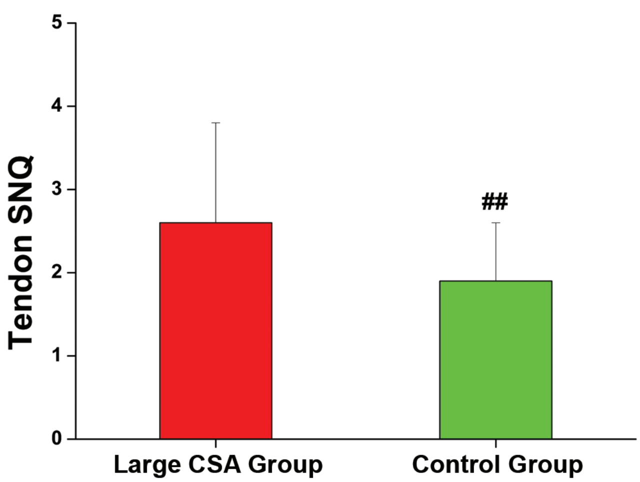

Figure 9. Comparison of tendon signal/noise quotient (SNQ) between the large critical shoulder angle (CSA) group and the control group. ##Significant difference between groups, P = .003. Values are presented as mean ± SD.

Constant, VAS, and strength occurred between the large AI group and the control group (Table 2). Postoperative MRI revealed 9 retear cases in the large AI group, which had a higher retear rate (13%) than the control group (0%) although without significant difference (P = .064). The postoperative tendon SNQ of the large AI group (2.6 ± 1.2) was significantly greater than that of the control group (1.8 ± 0.4, P = .002).

DISCUSSION

To date, a large number of researchers have investigated the integrity of the rotator cuff as well as the retear rate at follow-up.[2,5,15,18,20,35,41] The structural healing of the repaired rotator cuff to the anatomic footprint has traditionally been evaluated with MRI. In this study, tendon integrity and signal intensity were evaluated with 3.0-T MRI, and a significant correlation between tendon intensity and scapular geometry was observed. Particularly, a large CSA increased the risk of rotator cuff tendon retear after repair.

The present study revealed no significant association between CSA and functional factors (ASES, UCLA, Constant score, VAS, strength) for this cohort. Ames et al[1] observed that patients with a larger AI had slightly lower satisfaction scores, poorer physical health, and more disability than those patients with a small AI after surgical rotator cuff repair. Garcia et al[11] also demonstrated that large CSA correlated with worse postoperative functional scores. However, Kirsch et al[19] investigated the association between CSA and functional scores at 24 months after arthroscopic rotator cuff repair and found that CSA did not appear to be a significant predictor of patient-reported outcomes. Similarly, Lee et al[22] investigated the influence of CSA and AI on functional outcomes after arthroscopic rotator cuff repair, and they concluded that increased CSA and AI did not negatively influence functional outcomes at 24 months. The present study also indicated no significant difference in functional scores between the large CSA group and the control group. It was presumed that different results might occur due to different participant characteristics. The present study excluded massive RCTs and patients with glenohumeral osteoarthritis.

The current study also evaluated rotator cuff tendon integrity and signal intensity at a minimum follow-up of 2 years. After repair, the rotator cuff tendon would have a remodeling process with decreasing signal intensity during the first year postoperatively.[32] As with the anterior cruciate ligament graft in the knee joint, evaluation of the rotator cuff tendon graft after repair by MRI is much better and proper at 2 years postoperatively.[38] Boileau et al[4] evaluated rotator cuff repairs in a single study performed between 6 months and 3 years after surgery and concluded that the repair should be considered failed if footprint coverage is <50%. Crim et al[7] showed that this is not a good indicator of surgical failure. The footprint coverage may appear poor at 6 weeks or 3 months after surgery, and subsequent improvement of footprint coverage may occur by the end of the first postoperative

TABLE 2
Participant Characteristics Based on AI[a]

	Large AI (n = 67)	Control (n = 23)	*P* Value
Age, y	55.1 ± 7.1	55.8 ± 6.6	.696
Body mass index, kg/m^2	23.4 ± 3.0	22.3 ± 2.6	.134
Sex			.932
Male	14	5	
Female	53	18	
Side			.211
Left	25	12	
Right	42	11	
Tear size, cm	2.8 ± 1.0	2.6 ± 0.8	.403
Repair technique			.539
SR	30	12	
DR	37	11	
Follow-up time, mo	33 ± 11 (24~73)	39 ± 14 (24~78)	.040
CSA, deg	44 ± 5	35 ± 2	< .001
AI	0.81 ± 0.06	0.66 ± 0.04	< .001
ASES	87.8 ± 9.7	87.7 ± 11.2	.993
UCLA	30.8 ± 2.9	31.0 ± 3.2	.822
Constant	74.4 ± 7.9	77.6 ± 6.9	.085
VAS	1.4 ± 1.4	1.4 ± 1.4	.961
Strength	8.0 ± 3.5	7.7 ± 3.4	.731

[a]Values are presented as mean ± SD or n. AI, acromial index; ASES, American Shoulder and Elbow Surgeons; CSA, critical shoulder angle; DR, double row; SR, single row; UCLA, University of California at Los Angeles; VAS, visual analog scale.

year. It was suggested that during the first postoperative year, it is not prudent to consider the tendon repair as failed according to tendon irregularity, thinning, or increased signal intensity. During the first year after repair, supraspinatus tendons exhibited high signal intensity on MRI in 90% of clinically improving patients, and the increased signal intensity and thickness of the repaired tendon decreased, suggesting a gradual healing process rather than a retear.[21] Recurrent defects after arthroscopic reconstruction of supraspinatus tears in a modified suture bridge technique seem to occur between 12 and 24 months after surgery.[36] Thus, it is proper to evaluate the MRI appearance of the repaired tendon at 2 years after rotator cuff repair.

In the present study, postoperative MRI revealed that the large CSA group had a significantly higher retear rate (15%) and greater tendon SNQ than the control group. The increased CSA was a risk factor for a rotator cuff retear. During the past few years, many researchers have investigated the retear rate after rotator cuff repair.[9,13,14,18] Some factors, such as age, initial tear size, and fatty degeneration of the supraspinatus, were found to be independent risk factors for a rotator cuff retear.[24] Zumstein et al[42] reported that shoulders with a retear had a significantly higher mean AI than those without retear, and they identified an increased AI as a risk factor for retear. Garcia et al[11] recently investigated the retear rate of the repaired rotator cuff tendon with ultrasound and found that the retear tendon group had a larger CSA than the group with normal tendons. The authors indicated that larger CSA significantly increased the risk of a tendon retear after rotator cuff repair.

Furthermore, tendon SNQ was analyzed to represent tendon quality, and greater SNQ indicated poor tendon quality.[26] The authors of the current study found that the postoperative tendon SNQ of the large CSA group was significantly greater than that of the control group, indicating poorer tendon quality in the former. Previous biomechanical studies suggested that each increase in CSA is associated with a significant increase in cranially directed shear forces. Gerber et al[12] reported that a high CSA could induce supraspinatus overload, particularly at low degrees of active abduction. The increased compensatory activity of the rotator cuff tendon may result in mechanical overload of the tendon and could explain the clinically observed association between large CSA angles and degenerative RCTs.[28,39] It was reasonably presumed that the repaired rotator cuff tendons in patients with larger CSAs would still be under relatively higher load and reveal a higher signal intensity as compared with those in patients with lower CSA.

There are several limitations in the current study. First, the sample size of the patients included and analyzed was small. As this is a retrospective study, the number of patients recruited was not large, which might have introduced bias and inaccuracy. Additionally, 2 repair techniques were applied in this study (single and double row). It was unclear if the repair techniques influenced the results. However, most previous studies reported no significant difference in clinical score or function between the single- and double-row repair groups.[3,14,30] Moreover, the anterior-posterior radiographs were not true but conventional anterior-posterior radiographs, with some internal rotation of the glenoid. However, it was reported that the CSA with a malrotation <20° is almost stable and that the influence of rotation is negligible.[27] Finally, the postoperative rehabilitation program was a standardized one. We did not take individual conditions into account, which might undermine the functional recovery and quality of tendon healing, especially for those who had a poor quality of tendon.

CONCLUSION

This study revealed that CSA did not appear to influence postoperative functional outcomes, while patients in the large CSA group had significantly poor tendon integrity after rotator cuff repair. These findings indicate that a large CSA was associated with an increase in the risk of rotator cuff tendon retear after repair.

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