

Research Article

Evaluation of critical shoulder angle and acromion index in patients with anterior shoulder instability and rotator cuff tear

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ABSTRACT

Objective: The aim of this study was to evaluate glenohumeral morphologic differences and their correlation between glenohumeral instability and rotator cuff pathology.

Methods: Two-hundred radiographs and 100 MRI scans of 100 patients in whom the diagnosis of Anterior Shoulder Instability (AnI) or Rotator Cuff Tear (RCT) was arthroscopically verified were retrospectively identified and included in the study. All the patients were categorized into two groups: 50 patients with AnI (23 female, 28 male; mean age = 29 ± 7.4) and 50 patients with RCT (28 female, 22 male). Two separate control groups were then formed, one of which included contralateral shoulders of patients in the AnI group, and the other consisted of contralateral shoulders of patients in the RCT group. The x-ray and MRI scans were examined by an orthopedic surgeon and a radiologist. The Acromial Index (AI) and the Critical Shoulder Angle (CSA) were measured on true anteroposterior shoulder radiographs; Glenoid Inclination (GI), Glenoid Version (GV), and Acromion Angulation (AA) were measured on MRI.

Results: In the AnI group, the measurements were as followed: AI, 0.66 ± 0.03 ; CSA, $33^\circ \pm 2.85$; GI, $3.4^\circ \pm 6.2$; GV, 4.1 ± 4.3 ; and AA, 12.9 ± 8.3 . In the RCT group, AI 0.71 ± 0.04 ; CSA, $36^\circ \pm 2.69$; GI, 9.1 ± 5 ; GV, $6.7^\circ \pm 5.7$; and AA, $14.3^\circ \pm 8.7$. A moderate correlation was found between CSA and GI ($r = 0.41$, $P = 0.001$) and between AI and GI ($r = 0.42$, $P = 0.014$). A weak correlation was found between AI and GI in the AnI group ($r = 0.22$, $P = 0.001$). The inter- and intra-observer intraclass correlation coefficients were respectively 0.81 and 0.84 for AI, 0.88 and 0.92 for CSA, 0.72 and 0.76 for GI, 0.69 and 0.73 for GV, and 0.72 and 0.77 for AA.

Conclusion: The results of this study have shown that lower AI, GI, and antevert GV may be associated with AnI. Investigating CSA, AI, and GV could be useful for diagnostic evaluation of patients with AnI.

Level of Evidence: Level III, Diagnostic Study

Introduction

The Acromial Index (AI) is used to evaluate the lateral extension of the acromion. In Rotator Cuff Tears (RCTs), the shape of the acromion causes the origin of the deltoid to be more lateral, thereby producing a force with a more ascendant orientation, which probably favors subacromial impact. The Critical Shoulder Angle (CSA) is the combination of Glenoid Inclination (GI) and AI.¹ It has previously been demonstrated that AI and CSA were higher in patients with RCT.² CSA and AI have been demonstrated to be predictive factors of RCT, and larger CSA and AI are associated with higher rates of rotator cuff retear after surgery.³ However, these results are still controversial because there are studies showing no association between CSA, AI, and RCT.^{4,5} Studies that evaluate CSA and AI in patients with AnI are limited. However, in a biomechanical study, the inclination-dependent changes in CSA affect the glenohumeral joint stability.⁶ No

radiological or clinical study has investigated the relationships between CSA, AI, and AnI. Thus, the relationships between CSA, AI, and AnI have to be clarified with radiological and clinical studies.

Anterior Shoulder Instability (AnI) and RCT are related to changes in the glenohumeral morphology, such as Glenoid Version (GV), GI, and humeral head diameter.^{7,8} GI is a part of CSA and AI, and the humeral head diameter is a part of AI. As studies have shown, GI and GV in patients with RCT or AnI are different from those in normal population^{9,10} and the humeral head is smaller in RCTs and larger in AnI.^{8,11} These results may suggest that CSA and AI can also be different between patients with RCT and those with AnI. Thus, the roles of CSA, AI, GI, and GV are not fully evaluated in patients with AnI.

A hooked-type acromion has been shown to be related to RCTs.¹² An acromion with a flattened slope on

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lateral radiography has been shown to be related to impingement syndrome.¹³ The Acromial Angle (AA), which represents the coronal slope of acromion, has been shown to be related with RCT because of the narrowing of the acromiohumeral distance.^{14,15} Studies that evaluated the relationships between AA and AnI and RC are limited, and the AA in patients with anterior shoulder instability (AnI) has not been fully elucidated.

We aimed to answer the following three questions: (1) "Are AI and CSA reliable radiological parameters of AnI?," (2) "Are there any relationships between GI, GV, CSA, and AI?," and (3) "Are there any relationships between AA and AnI and AA and RCT?" Therefore, we analyzed acromial and glenohumeral morphological parameters on radiographs and Magnetic Resonance Imaging (MRI) scans and evaluated five different radiographic measurements (CSA, AI, GI, GV, and AA), which might be related to shoulder pathologies such as AnI and rotator cuff injury.

Materials and Methods

This retrospective study was approved by Local Ethical Committee of Fatih Sultan Mehmet Training and Research Hospital (2019, No: 22), who waived the requirement for informed consent.

Patient selection

We retrospectively reviewed the examination, radiography, and MRI records of 680 consecutive patients who were arthroscopically verified to have AnI or RCT. All the patients were referred to our clinic between 2013 and 2019. Patients with available information on age, sex, side affected, occupation (past and current jobs), sport activity level (classified as sedentary, recreational, and professional), history of trauma, active-passive shoulder Range of Motion (ROM), and muscle strength were included in this study. The exclusion criteria for all groups were rheumatologic diseases; significant degenerative arthritis in the glenoid, humerus, and acromioclavicular joint on preoperative radiography and MRI (Walch type B and C glenoid deformities, Hamada classification 2 to 5)^{16,17}; osteonecrosis; pathological neurological findings; tissue disorders; heavy labor (occupations were subjectively classified as light, intermediate, and heavy); professional athletes or those with recreational sporting activities related to the shoulder; calcific tendinitis; under the age of 15 years; grade 3 or 4 cartilage damage; a sequel of infections; fractures around the shoulder girdle; and previous shoulder surgery. After application of the exclusion criteria, 345 patients remained for the analysis.

In the AnI group, we evaluated the preoperative radiographic images of patients who had symptomatic recurrent AnI confirmed by preoperative MRI and physical examinations and underwent arthroscopic stabilization surgery. The exclusion criteria for this group were the presence of track shoulder lesion; positive impingement sign; glenoid defect >25%; concomitant intra-articular lesion (eg,

Superior Anterior Labral Tear [SLAP]) or Humeral Avulsion of the Glenohumeral Ligament (HAGL); weaker muscle strength in abduction and external rotation; active and passive limited ROM; and multidirectional or atraumatic shoulder instability and RCTs. On- and off-track shoulder lesions were determined arthroscopically. Impingement signs were examined in accordance with the Neer classification.¹⁸

In the RCT group, we evaluated the preoperative radiographic images of the patients who had symptomatic full-thickness RCTs (supra-infraspinatus tendons) confirmed by preoperative MRI and physical examinations and underwent arthroscopic stabilization surgery. The exclusion criteria for this group were operative findings with included subscapularis tendon tear; massive RCTs extending into the teres minor; coexisting labral tears; SLAP; and rotator cuff arthropathy and HAGL.

Two separate control groups were formed, the contralateral shoulders of the patients in the AnI group included as the AnI control group and the contralateral shoulders of the patients in the RCT group included as the RCT control group. The shoulders of the patients that were included in the control group had completely normal examination results. No MRI assessment was performed for the control groups, as no reason for examination of the contralateral shoulder was found.

After application of the exclusion criteria in each subgroup, 50 patients were left for each group. We performed a prior power analysis and determined that a sample size of 43 for each group would be sufficient.

Radiographic and MRI assessment

The preoperative radiography and MRI scans were reviewed blindly by a radiologist with special expertise in musculoskeletal imaging and an associate professor with >10 years of orthopedic experience.

Radiographic assessment

All the patients underwent preoperative standardized true anteroposterior radiography, and their radiographs were made digitally available. The medical imaging program (DataMed Angora, Ankara, Turkey) was used to assess the digital angle. According to Nyffeler et al.,¹⁹ the humeral head was required to be in a neutral position or up to a maximum of 20° internal rotation to be included in the definition of a true anteroposterior radiograph. The supplementary scapula position must not exceed 20° of either the external or internal rotation.¹ Deviations smaller than these threshold values were confirmed as irrelevant in previous studies.^{1,19}

The CSA was measured consistent with guidelines set by Moor et al. using a line connecting the superior and inferior bone margins of the glenoid, intersecting with a line drawn from the inferior bone margin of the glenoid to the most lateral border of the acromion¹ (Figure 1).

AI was measured consistent with the method described by Nyffeler et al. as follows: AI was derived by measuring the distance from the glenoid plane to the lateral border of the acromion (GA) and dividing it by the distance from the glenoid plane to the lateral aspect of the humeral head (GH)¹⁹ (Figure 2).

MRI assessment

All shoulder MRIs were acquired in our hospital using an Optima MR450w 1.5-Tesla scanner (General Electric, IL, USA). All the images were obtained with the patient in the supine position, the arm placed on the side of the body, the forearm supinated, and the hand under

HIGHLIGHTS :

- The AI was lower in the AnI group than in the control group.
- The GI was significantly lower in the AnI group than in the RCT group. In addition, the GV was significantly lower in the AnI group than in the RCT group. A moderate correlation was observed between CSA and GI. A moderate correlation was observed between AI and GV.
- CSA and AI were significantly higher in the RCT group than in the control group.
- The AA was significantly lower in the AnI group than in the RCT group. No correlation was found among AA, CSA, and AI in both groups.

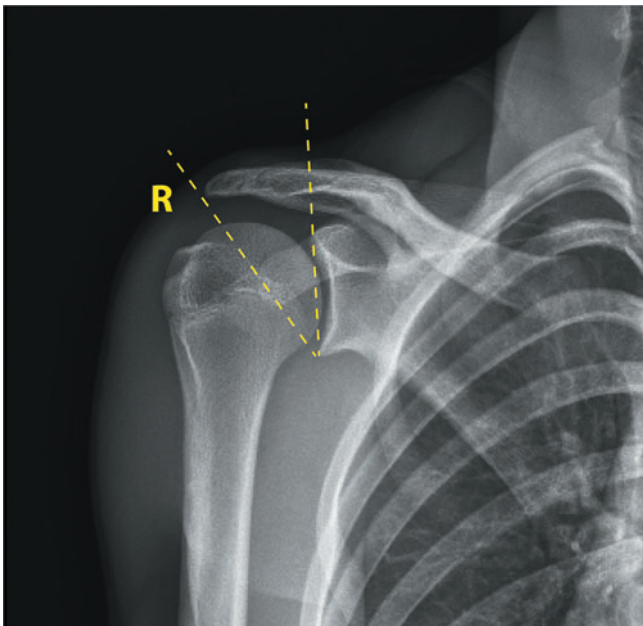


Figure 1. The most superior and inferior points of the glenoid fossa and the most inferolateral point of the acromion are marked. The angle represents CSA.

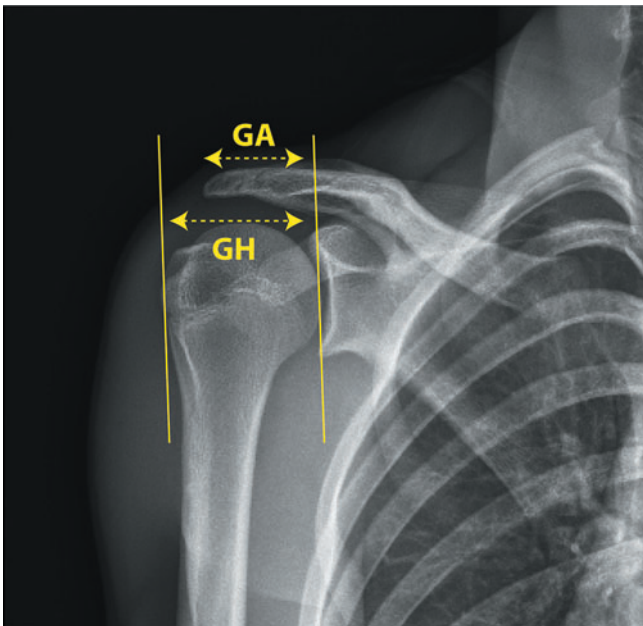


Figure 2. AI was defined as the ratio of the distance from the glenoid plane to the lateral acromion to the distance from the glenoid plane to the lateral aspect of the humeral greater tubercle.

the hip to maintain a humeral position during the examination. For the MRI protocol, a 4-mm thin coronal section was taken, and sagittal turbo-spin echo proton density-weighted images (WI), T2-WIs, coronal STIR sequences, and oblique coronal images were used. The coronal oblique images were taken in a plane parallel to the supraspinatus tendon.⁹

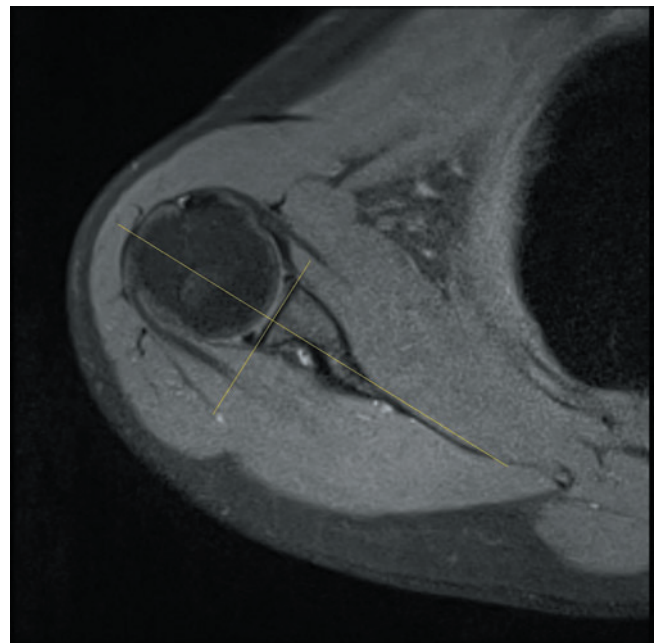


Figure 3. An axial MRI of a patient with anterior shoulder instability. A line drawn from the anterior and posterior glenoid rim points of the glenoid fossa and the line drawn from posterior glenoid neck to the scapular body medially are shown. The angle represents the glenoid version.

The GI, GV, and AA were measured for each patient in the AnI and RCT groups.

GV was measured as defined by Tetreault et al. using a line connecting the anterior and posterior glenoid rims and intersecting with a line drawn from the posterior glenoid neck to the scapular body medially on an axial image. GV was calculated by subtracting 90° from the angle formed by the glenoid surface and the scapular body. Retroversion was defined as a positive angle; and anteversion, as a negative angle¹⁰ (Figure 3).

GI was measured as defined by Maurer et al. using a line connecting the upper and lower glenoid rims, intersecting with the scapular body line in the coronal oblique image, which displays the deepest point of the supraspinatus fossa. GI was calculated by subtracting 90° from the angle formed by the glenoid surface and scapular body. The upward- and downward-oriented glenoid angles were defined as positive and negative angles, respectively²⁰ (Figure 4).

Acromion angulation (AA) was measured as defined by McGinley et al. using a line connecting the lower surface of the acromion and the horizontal line in the coronal oblique image. The upward-oriented acromion was defined as a positive angle; and the downward-oriented acromion, as a negative angle¹⁵ (Figure 5).

Statistical analysis

Statistical analysis was performed using the SPSS version 25 software (IBM Corporation, Armonk, New York, United States). Data were analyzed using descriptive statistics (mean, standard deviation, median, frequency, percentage, minimum, and maximum). The normal distribution of the data was evaluated using the Shapiro-Wilk test. Variance homogeneity was assessed using the Levene test. The inter-observer and intraobserver reproducibilities were determined using

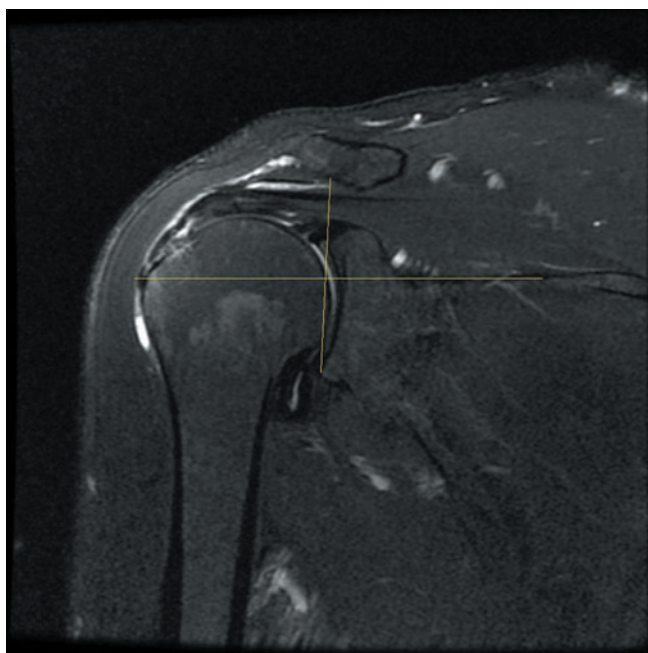


Figure 4. A coronal oblique MRI of a patient with a rotator cuff tear. A line drawn from the upper and lower glenoid rim points of the glenoid fossa, and a line drawn from the scapular body line in the deepest point of the supraspinatus fossa are shown. The angle represents the glenoid inclination.

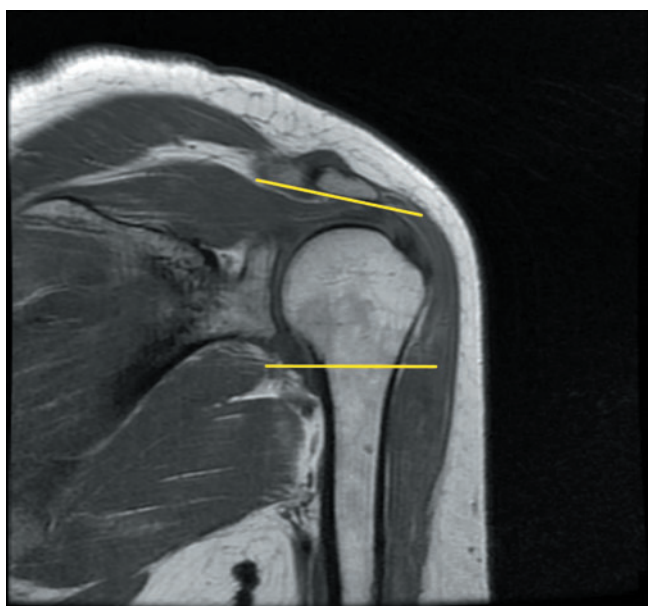


Figure 5. A coronal oblique MRI of a patient with anterior shoulder instability. A line drawn between the lower surface of the acromion and the horizontal line. The angle represents the acromion angulation.

Intraclass Correlation Coefficients (ICCs). The Mann-Whitney *U*-test was used for the comparison of the two groups that did not show a normal distribution. Spearman correlation coefficients were calculated to analyze the relationship. They were categorized according to Dancy and Reidy grading system as follows: 0, none; 0.1–0.3, weak; 0.4–0.6, moderate; 0.7–0.9, strong; and 1, perfect.¹⁵ A *P* < 0.05 was considered statistically significant.

Table 1. The Distribution of Descriptive Characteristics of Two Groups

Groups	Anterior instability (n = 50)	Rotator cuff (n = 50)	<i>P</i>
Gender:			
Female	23(%46)	28(%56)	0.697
Male	27(%54)	22(%44)	
Side:			
Right	28(%56)	31(%62)	0.251
Left	22(%44)	19(%38)	
Age (years)			
Mean ± SD	29 ± 7.4	54.6 ± 9.05	<0.001
Range	18–44	38–69	

Mann-Whitney *U*-test
SD, Standard Deviation.

Results

In total, we examined 200 radiographs of 100 patients (including the contralateral sides), and the MRI scans of 100 patients were included in the study. The patients in the two groups differed demographically (Table 1).

The mean age of the patients was higher in the RCT group (54.6 ± 9.05 years) than in the AnI group (29 ± 7.4 years; *P* < 0.001). We found no significant differences between the groups with regard to sex (*P* = 0.697) and side of injury (*P* = 0.251).

Objective 1: The AI in the AnI group is lower than those in the control and RCT groups. We found no significant difference in CSA between the AnI and control groups.

With regard to bilateral comparisons, CSA in the RCT group (36° ± 2.69) was significantly higher than those in the AnI (33° ± 2.85) and RCT control groups (34° ± 4.16; *P* = 0.001 and *P* < 0.05, respectively). No significant difference was found between the AnI and AnI control groups (33° ± 3.22; *P* > 0.05; Table 2). We found no significant difference in CSA according to sex or side of injury (*P* = 0.124 and *P* < 0.05, respectively).

With regard to bilateral comparisons, AI in the AnI group (0.66 ± 0.03) was significantly lower than those in the RCT group (0.71 ± 0.04; *P* = 0.001 and *P* < 0.05, respectively) and AnI control group (0.68 ± 0.04; *P* = 0.034 and *P* < 0.05, respectively). The RCT control group (0.69 ± 0.03) also had lower AI than the RCT group (*P* = 0.038 and *P* < 0.05, respectively; Table 3). We found no significant difference in AI according to sex or side of injury (*P* = 0.251).

Objective 2: The GI in the AnI group was found to be significantly lower than that in the RCT group. A correlation was observed between GI and CSA and between GI and AI in both the RCT and AnI groups. A correlation was also found between GV and CSA and between GV and AI only in the AnI group.

The GI in the AnI group (3.40° ± 6.20) was significantly lower than that in the RCT group (9.1° ± 5; *P* < 0.001). The GV in the AnI group (4.1° ± 4.3) was significantly lower than that in the RCT group (6.7° ± 5.7; *P* < 0.001).

A moderate correlation was observed between CSA and GI (*r* = 0.41, *P* = 0.001). In the AnI group, the correlation between CSA and GI was significantly less in in RCT group (29% vs 55%). A moderate correlation was observed between AI and GI (*r* = 0.42, *P* = 0.014). In the AnI group, the correlation between AI and GI was significantly less than in the RCT group (25% vs 57%). We found no correlation between total CSA and GV and between total AI and GV (*P* = 0.28

Table 2. The Glenohumeral Morphological Parameters

		CSA (mean ± SD) (range)	AI (mean ± SD) (range)	GI (mean ± SD) (range)	GV (mean ± SD) (range)	AA (mean ± SD) (range)
Anterior instability group	AnI	33 ± 2.85 (25–37)	0.66 ± 0.03 (0.62–0.71)	3.4° ± 6.2°(–3.5 to 21)	4.1° ± 4.3°(–6.7 to 16.1)	12.9 ± 8.3(–16–42)
	AnI control	33 ± 3.22 (26–40)	0.68 ± 0.04 (0.63–0.72)			
Rotator cuff tear group	RCT	36 ± 2.69 (29–46)	0.71 ± 0.04 (0.65–0.76)	9.1° ± 5°(–4.3 to 23.2)	6.7° ± 5.7°(–5.2 to 18.3)	14.3 ± 8.7(–18–43)
	RCT control	34 ± 4.16 (28–45)	0.69 ± 0.03 (0.64–0.72)			

CSA, Critical Shoulder Angle; AI, Acromion Index; GI, Glenoid Inclination; GV, Glenoid Retroversion; AA, Acromion Angulation.

Table 3. The Comparison of Glenohumeral Morphological Parameters

*P	AnI-RCT	AnI-N1	RCT-N2	N1-N2
Critical shoulder angle	0.001	0.69	0.001	0.34
Acromion index	0.001	0.034	0.038	0.42
Glenoid inclination	0.001			
Glenoid retroversion	0.001			
Acromion angulation	0.001			

*Mann-Whitney U-test.

AnI, Anterior Instability Groups; RCT, Rotator Cuff Groups; N1, AnI Control Group; N2, RCT Control Group.

Table 4. Correlations of Morphological Parameters

	r	p
CSA-GI		
Anterior instability	0.29	0.017
Rotator cuff tear group	0.55	0.001
Total	0.41	0.001
CSA-GV		
Anterior instability	0.28	0.001
Rotator cuff tear group	0.55	0.33
Total	0.59	0.28
AI-GI		
Anterior instability	0.25	0.01
Rotator cuff tear group	0.57	0.001
Total	0.42	0.014
AI-GV		
Anterior instability	0.22	0.001
Rotator cuff tear group	0.47	0.42
Total	0.44	0.09
CSA-AA		
Anterior instability	0.44	0.18
Rotator cuff tear group	0.26	0.42
Total	0.38	0.25
AI-AA		
Anterior instability	0.75	0.141
Rotator cuff tear group	0.28	0.38
Total	0.44	0.11

* Spearman correlation coefficients.

and $P = 0.31$, respectively). In the AnI group, CSA and GV and AI and GV showed significantly weak correlations (28% and 22%, respectively; Table 4).

Objective 3: The AA in the AnI group was significantly lower than that in the RCT group. We found no significant correlation between AA and CSA and between AA and AI.

The AA in the AnI group (12.9 ± 8.3) was significantly lower than that in the RCT group (14.3 ± 8.7 ; $P < 0.001$). No correlation was observed between AI and AA and between CSA and AI in the RCT group ($P = 0.38$ and $P = 0.42$, respectively). Also no correlation was found between CSA and AA and between AI and AA in the AnI group ($P = 0.18$ and $P = 0.141$, respectively). No correlation was observed

between total CSA and AA and between total AI and AA ($P = 0.11$ and $P = 0.09$, respectively; Table 4).

An ICC value of 0.9 was considered excellent, and the values between 0.8 and 0.9 were considered good. The interobserver and intraobserver ICCs were 0.81 and 0.84 for AI, 0.88 and 0.92 for CSA, 0.72 and 0.76 for GI, 0.69 and 0.73 for GV, and 0.72 and 0.77 for AA, respectively.

Discussion

The most important finding of our study is that the AI in the AnI group was lower than that in the control group, and no significant difference in CSA was found between the AnI control and AnI groups. These data support our hypothesis in confirming a relationship between the AI and AnI groups. CSA and AI were significantly higher in the RCT group than in the RCT control group, consistent with previous studies.² The GI was anteverted in the AnI groups, and the GV in the AnI group was found to be significantly lower than that in the RCT group. These results are similar to those reported in the literature.^{9,21} A moderate correlation was observed between CSA and GI. No correlation was found between total CSA and GV and between total AI and GV. In the AnI group, a weak correlation was observed between CSA and GV and between AI and GV. The AA is down-oriented in the RCT group. We found no correlation between AA and CSA, and between AA and AI.

According to an MRI study, the humeral head is larger in both the transverse and longitudinal axes in the AnI group, but smaller both transversely and longitudinally in the rotator cuff group⁸ and is consistent with a CT study that showed that the humerus is larger in both the vertical and horizontal planes in the AnI group.¹¹ We believe that AI was smaller in the AnI group because the humeral head was larger, and AI was larger in the RCT group because the humeral head was smaller than that in the control group. In our study, we found that AI was lower in the AnI group than in the AnI control group. However, a previous work showed a high correlation between CSA and AI in patients with RCT.²² We found no significant differences between the AnI and AnI control groups in terms of CSA, which depends on the glenoid height and GA. The literature shows no significant differences between AnI and control groups in terms of glenoid height.²³ In our study, CSA was not different between the AnI and AnI control groups, which suggests that the lower AI in the AnI group than in the AnI control group could be more related to the increase in GH rather than the increase in GA. More morphological studies are needed to confirm this inference.

Some studies showed that AI was higher in patients with RCT than in controls.^{2,19,24} By contrast, studies showed no significant differences between the RCT and control groups.^{5,25} In the literature, whether AI is the cause of RCT and AnI is controversial. However, no study in the literature has evaluated the relationship between AI and AnI. In our study, AI evaluation revealed significant differences among all three groups, and AI was significantly higher in the RCT group than in the control group. Therefore, AI could be considered a predisposing

factor for RCT and AnI. Miyazaki et al. showed that AI was associated with RCT in the Brazilian population, but no relationship was observed in the Japanese population.²⁶ Kum et al. showed a correlation with RCT in the Korean population, but no relationship with tear size.²⁷ Each ethnic group has its own characteristics, and the differences between the results may come from a factor related to the biotype of each ethnic group, especially AI measurement. AI was not related to tear size.

In recent studies, CSA measurement was found highly useful for diagnosing RCT on plain radiographs. Normal CSA values are between 30° and 35°, with values smaller than 30° associated with glenohumeral osteoarthritis and values higher than 35° associated with RCT.^{1,28} In our study, the mean CSA was significantly higher in the RCT group (36°) than in the AnI and control groups. This value is similarly consistent with the values reported by Moor et al. (38°),¹ Scheiderer et al. (37°),² Spiegl et al. (37.3°),²⁹ and Dagget et al. (37.9°).³⁰ Higher CSA values were found to be associated with RCT, but in our study, no association between AnI and CSA was found.

The CSA plays an important role in balanced mechanical loading of the glenohumeral joint.^{1,10,19,31} CSA is a measurement that combines lateral acromial offset and GI. A more lateral acromial offset creates a more lateral deltoid origin and, in theory, results in greater shear, less compressive vector of the deltoid across the glenohumeral joint, and a concomitant increased requirement for supraspinatus force to stabilize the humeral head.³² Similarly, Gerber et al. found that a smaller CSA was associated with greater compressive joint forces and lower shear forces, especially during early abduction. Consequently, a large CSA (38°) when compared with a smaller control CSA (33°) led to a greater instability ratio (defined as joint shear-to-joint compression force ratio) between 6° and 61° abduction.³³

The relationship between GI and CSA is controversial. In some studies, a positive correlation was observed between GI and CSA in patients with RCT.^{30,34} By contrast, some studies showed no relationship between GI and CSA.^{35,36} However, a positive correlation was observed between GI and AI in the literature.^{30,37} In our study, we found a positive correlation between CSA and GI and between AI and GI. CSA is the combination of GI and AA, which are expected to be correlated.³⁷ Consistently, we confirmed the correlation between these anatomical parameters.

In previous studies, a relationship between GV and AnI was reported, and the glenoid was more anteverted in the AnI group than in the control groups.^{8,9} The relationship between GV and RCT is controversial. Some studies showed a relationship,³ but by contrast, some studies showed no relationship between GV and RCT.²¹ In our study, a control group with MRI evaluation was not included, but in the AnI group, the glenoid was found to be more anteverted than in the RCT group. This finding is consistent with those reported in the literature, and we found a weak correlation between CSA and GV and between AI and GV only in the AnI group. CSA is the combination of GI and GA.³⁷ A true anteroposterior radiograph perspective is related to GV and >2° deviation in GV affects CSA.³⁸ Thus, we think that GV changes may have an effect on acromion lengths, so this may have affected the results of the CSA measurements in the AnI group. However, this conclusion must be corrected in future studies comparing the RCT and AnI groups with the normal population in terms of GV.

The acromial shape can affect the subacromial distance. A positive relationship was observed between high AA and full-thickness RCT because the subacromial distance narrows.^{3,14} Similarly, in our study,

AA was found to be higher in the RCT group than in the AnI group. CSA is the combination of GI and AA, which are expected to be correlated.³⁷ However, we did not observe any correlation between the measurements.

Humeral head and glenoid bone defects have been observed in 44% of patients with AnI who had <5 dislocations.³⁹ To evaluate the humeral head and glenoid bone defects, on- and off-track shoulder lesions have been described.⁴⁰ In off-track lesions, larger bone defects were observed in the humeral head and on the glenoid side.⁴⁰ These defects could affect radiological measurements such as CSA and AI. Thus, the size of these defects may have an effect on the measurements. Only patients with on-track lesions were included in our study because the number of patients who had off-track shoulder lesions was limited. Studies with large numbers of patients for investigating on-track and off-track shoulder lesions are needed to evaluate the effect of bone defects on these measurements.

In our study, conventional radiography was chosen over MRI because CSA measured using MRI has been shown to have higher variability and poorer intraobserver reliability than CSA measured on conventional radiography.²⁹ In a study that used conventional radiography, the CSA intraobserver reproducibility was 96.7% and the interobserver reproducibility was 95.5%.⁴¹ In another study, AI and CSA were all >0.90, which suggests high intraobserver and interobserver reliabilities.⁴² In another study, the AI intraclass correlation coefficient was 82%.²⁷ This value is consistent with those reported in the literature. In this study, GI was measured on MRI instead of on radiography because on MRI, the GI inclination measurements are independent of the scapular position. GI measurement on radiography could cause differences from those on MRI.^{21,43}

Our study had several limitations that warrant discussion. First, it was a retrospective study with a relatively small sample size; thus, caution should be observed when generalizing these data to the entire population. A slight age-related difference was observed between the RCT and AnI groups. Second, all the patients were of Caucasian descent. Third, the radiologist was blinded to the outcomes of each patient to prevent bias, but technical errors could have been made while taking the true AP radiographs to assess the CSA and AI. Fourth, not MRI control group was included in our study because of its retrospective nature. Fifth, CT is the gold standard for GV and GI, but we used MRI to evaluate GI and GV because MRI is often used to diagnose RCT and AnI. Finally, glenoid and acromion shapes could be affected during the natural progression of shoulder disease, especially in RCT.

The first important finding of our study, which differs from the literature, is that AI in the AnI group was lower than in the AnI control group because there is no study evaluating AI in patients with anterior instability in the literature. The second important finding is that no significant difference was observed between CSA measurements in the AnI group compared to the AnI control group contrary to the literature.⁶

In conclusion, lower AI, GI, and anteverted GV are associated with AnI. GI is linearly correlated with CSA and AI. AA is not correlated with CSA and AI. Investigating the CSA, AI, and GV could be useful for the diagnostic evaluation of patients with AnI. Our findings do not fully explain the cause of AnI. CSA, AI, and GV may be associated with a greater dislocation rate and may influence functional outcomes. Further studies are needed to evaluate the clinical usefulness and roles of AI, AA, GI, and GV in the diagnosis and surgical management of AnI. We found similar results in the literature for the RCT

group; that is, higher AI, GI, and downside AA are associated with RCT.

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