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Evaluation of anatomical variations with morphological measurements and their relationship with rotator cuff tear and acromion types

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ABSTRACT

Introduction: There many more anatomical measurements such as the acromiohumeral distance and lateral acromion angle and acromial configuration was reported as might be associated with rotator cuff tear. In our study, we aimed to reveal the effect of acromion index, acromiohumeral distance, lateral acromion angle, critical shoulder angle values and the acromion type in the development of rotator cuff tear.

Material and Method: In our retrospective study, 58 patients and 29 asymptomatic volunteers who underwent shoulder magnetic resonance imaging examinations were examined. acromion index, acromion humaral distance, lateral acromion angle and critical shoulder angle were measured and their relationship with rotator cuff tear and acromion types were evaluated.

Results: Type III (hooked) of acromial shapes, higher acromion index and critical shoulder angle values, lower acromiohumeral distance and lateral acromion angle values are more frequently seen in rotator cuff tear patients, in our study.

Conclusion: Thus, we revealed anatomical malformations that predispose to rotator cuff tear concerning the shoulder joint.

Keywords: Shoulder joint, acromion types, rotator cuff tears

INTRODUCTION

The acromion is an important anatomical structure that exists in various configurations and some of these variations may lead to rotator cuff tear (RCT) (1). RCT is a frequently seen disease of shoulder, Almost 35% of patients undergoing magnetic resonance imaging (MRI) with shoulder pain have RCT. This rate reaches 50% in patients over the age of 66 (2). MRI enables a more comprehensive assessment of the glenohumeral joint by revealing the articular cartilage and labroligamentous structures in detail (3). Acromiohumeral distance (AHD) is measured as interval between the humeral head and the acromion (4). On MRI a narrowed AHD may cause decreased in lowering function of infraspinatus muscle and humeral head rise. Recently, narrowed AHD is found to be associated subacromial impingement and rotator cuff tear (4). Recently an relationship between the critical shoulder angle (CSA) and acromion index (AI) with RCTs were described (5). A high CSA (>35) was related to increased risk of RCT. Thus, shear forces apply an increasing force to the origin of the glenoid and rotator cuffs (5). As the lateral projection of the acromion increases, higher AI is measured (6). For this reason, increased AI is associated with RCT. There many more anatomical measurements such as the AHD and lateral acromion angle (LAA) and acromial configuration was reported as might be associated with RCT (1). In our study, we aimed to reveal the effect of AI, AHD, LAA, CSA values and the acromion type in the development of RCT.

MATERIAL AND METHOD

The study was carried out with the permission of Tokat Gaziosmanpasa University Hospital, Non-invasive Clinical Researches Ethics Committee (Date: 20.01.2022, Decision No: 2022/02). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

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General Data

In our retrospective study, 68 patients and 29 asymptomatic volunteers who underwent shoulder MRI examinations between 2019 and 2021 were examined. A total of 10 patients who have previous surgery, prosthesis, fractures or solid lesions involving shoulder joint, cases with acromial spurs or severe osteoarthritis, history of chemoradiotherapy, and known systemic disease were excluded from our study. Since our measurements were highly affected by shoulder and arm position, many patients without appropriate positioning on MRI were excluded from the study. During shoulder MRI, the patient is placed in supine position and the arm adducted with a mild external rotation.Fifty-eight patients with RCT and 29 asymptomatic volunteers were enrolled in this study. Patients are divided into two groups partial-thickness tear and full thickness tear on MRI. The supraspinatus, infraspinatus, subscapularis and teres minor muscles are evaluated as rotator cuff muscles. Full-thickness RCTs are accepted as the tears extends from the bursal surface to the articular surface. Partial-thickness RCTs are accepted as the tears lack of full transmural extension from the articular to the bursal surfaces. On fat-saturated PD or T2W images, tear is detected as fluid signal intensity within the tendon. Types of the acromion were evaluated on the T1W sagittal oblique images. The acromion has group into four type according to its shape (7). Type 1 acromion is described as flat. Type 2 is accepted as curved with a concave surface. Type 3 has a hooked shape in the most anterior portion of acromion. Type 4 was described as convex shaped acromion (**Figure 1**). All measurements are performed by a radiologist (S.Ö).

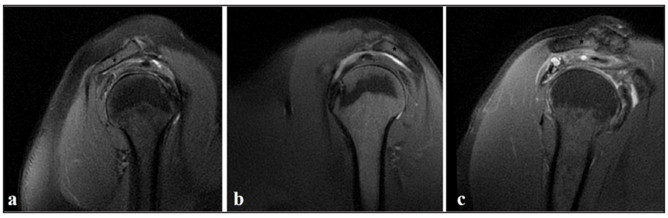


Figure 1. a) Type 1 acromion is described as flat. **b)** Type 2 is accepted as curved with a concave surface. **c)** Type 3 has a hooked shape in the most anterior portion of acromion (black star: acromion)

Measurements

In the coronal plane AI, AHD, LAA and CSA were measured (**Figure 2**). Measurements were obtained from the image where the lateral end of the glenoid and acromion could be seen simultaneously in the coronal section. The ratio between the distance from the glenoid cavity to the lateral edge of the humerus and the distance from the glenoid cavity to the lateral edge of the acromion is calculated as AI (8). To measure AHD two parallel auxiliary lines were drawn. First line placed on the lower edge of the acromion and second line is placed on the the osseous humeral head. The middle image of all images that represent the glenoid is chosen, on which the glenoid is shown larger (9). LAA was measured as the angle between the line passing through the middle of the joint and the line passing through the inferior surface of the acromion in the coronal plane where the acromioclavicular joint is best seen. CSA is measured as the angle between the superior and inferior bone margins of the glenoid and the most lateral border of the acromion (10). MRI image protocol was shown in **Table 1**.

Figure 2. a.) Acromiohumeral distance (AHD) is measured as interval between the humeral head and the acromion b.) Acromion index (AI) is calculated as the ratio between the distance from the glenoid cavity to the lateral edge of the humerus and the distance from the glenoid cavity to the lateral edge of the acromion. c.) Critical shoulder angle (CSA) is measured as the angle between the superior and inferior bone margins of the glenoid and the most lateral border of the acromion d.) Lateral acromial angle (LAA) was measured as the angle between the line passing through the middle of the joint and the line passing through the inferior surface of the acromion

Table 1. Pulse sequence

	FOV (cm)	Slice thickness (mm)	Matrix	TR/TE (ms)
Axial PD fat suppression	20x20	4	512×512	3000/77
Coronal oblique T1	20x20	4.5	512×512	700/9
Coronal oblique PD with fat suppression	20x20	4.5	512×512	2350/62
Sagittal oblique PD with fat suppression	20x20	4.5	512×512	2350/62

FOV: field of view, TE: echo time, TR: repetition time, cm: centimeter, mm: millimeter, ms: millisecond, PD: Proton density

Statistical Analysis

All statistical analysis was performed using R version 3.6.0 (The R Foundation for Statistical Computing, Vienna, Austria; https://www.r-project.org). Shapiro-Wilk's normality test and Q-Q plots were used to assess the normality of the data, and Levene's test was used to check the homogeneity of the variances. Numerical variables were expressed as mean±standard deviation, and estimated mean with 95% confidence intervals (CI) in case controlling for age. Categorical variables were described as count (n) and percentage (%). One-Way ANOVA (analysis of variances) and Welch's F test, and also independent sample t-test were used to compare the age, AI, AHM, LAA, and CSA values between the groups. The differences between the groups were investigated with Tukey HSD test after the ANOVA, and Games-

Howell multiple comparison test after the Welch's F test. Moreover, the analysis of covariance (ANCOVA) was run to determine the AI, AHM, LAA and CSA of study groups by controlling for age, since the age distribution of the groups were different. Multiple comparisons were performed with Bonferroni correction. Besides, Pearson chi-square test following by two proportion Z-test was applied to examine the association between study groups and gender distribution, and acromial shapes. The effect of the study groups on the acromial shapes was analyzed by multinomial logistic regression analysis by controlling for age. The receiver operating characteristic (ROC) curve analysis were conducted for AI, AHM, LAA, and CSA as a marker in diagnosing the RCT, and the area under the curve (AUC) values were calculated with 95% confidence intervals. An optimal cut-off values were determined using the Youden J index. The sensitivity, specificity, negative and positive predictive values were calculated with 95% confidence intervals for determined cut-off values. A p-value less than 5% was considered as statistically significant.

RESULTS

Fifty-eight patients with RCT were enrolled in this study. They were 31 (49.4%) females and 27 (50.6%) males. Their ages ranged from 23 to 81 years with a mean of 57.59±12.11 years. A control group of 29 asymptomatic volunteers without RCT was added. They were 12 females and 17 males. Their ages ranged from 21 to 68 years with a mean of 44.14±13.11 years. The mean age was 57.59±12.11 (ranged, 23-81) in RCT patients were higher than the healthy controls (44.14±13.11, ranged: 21-68, p<.001). However, the gender distribution of the groups was similar (p=.240). There was no statistically significant association between study groups and acromial shapes (p=.051). As a result of both ANOVA and age-adjusted ANCOVA analysis, AI and CSA values were significantly higher in patients with RCT compared to healthy controls, while AHM and LAA values were significantly lower (all p-values <.001, **Table 2**).

There was a significantly association between study groups and Type III (hooked) of acromial shapes, Type III proportion of acromial shapes was significantly higher in RCT patients than in healthy controls (n=14/58 [24.1%] vs. n=1/29 [3.4%], p=.031, **Table 3**). However, this association was not statistically significant when controlling for age (OR=3.68, 95% CI: 0.28-48.65, p=.323).

The mean and adjusted mean of the AI, AHM, LAA, and CSA values according to study groups were given in **Table 4**. A one-way ANOVA and Welch's F test were run to determine whether there was a statistically significant difference in AI, AHM, LAA and CSA values between study groups. There was a statistically significant difference in AI, AHM, LAA and CSA values between study groups (all p<.001). But, since the age distributions between the groups were different, a one-way covariance (ANCOVA) analysis was conducted to compare the AI, AHM, LAA and CSA of study groups by controlling for age. There was a significant difference in AI values between the study groups ($F_{2,83}$=22.86, p<.001, η^2=0.36). Post-hoc analysis, which is performed with a Bonferroni adjustment, showed that the AI values in patients with full thickness tear was (0.69, 95% CI:0.66-0.71) higher than patients with partial thickness tear (0.63, 95% CI: 0.61-0.66, adj. p=.005) and healthy controls (0.57, 95% CI: 0.54-0.59, adj. p<.001). In addition, the AI values were significantly higher in patients with

Table 2. Demographical characteristics and acromial measurements of the study groups

	Healthy controls (n=29)	RCT patients (n=58)	p-value
Age (years)	44.14±13.11 (21-68)	57.59±12.11 (23-81)	<.001[1]
Gender (Female/Male)	12/17	31/27	.240[2]
Acromial shapes			.051[2]
Type I (flat)	9 (31)	16 (27.6)	
Type II (curved)	19 (65.5)	28 (48.3)	
Type III (hooked)	1 (3.4)	14 (24.1)	
AI			
Mean±SD	0.57±0.05	0.66±0.06	<.001[1]
Estimated mean (95% CI)	0.57 (0.55-0.60)	0.66 (0.64-0.67)	<.001[3]
AHM (mm)			
Mean±SD	8.45±1.13	6.32±1.38	<.001[1]
Estimated mean (95% CI)	8.23 (7.72-8.74)	6.43 (6.08-6.77)	<.001[3]
LAA°			
Mean±SD	77.07±4.20	69.64±5.25	<.001[1]
Estimated mean (95% CI)	76.99 (75.01-78.98)	69.68 (68.32-71.03)	<.001[3]
CSA°			
Mean±SD	31.25±1.88	34.38±2.27	<.001[1]
Estimated mean (95% CI)	31.55 (30.70-32.40)	34.68 (34.10-35.26)	<.001[3]

Data were presented as mean±standard deviation (range) and estimated mean with 95% confidence intervals, and also were described as count (n) and percentage (%). Bold values denote that statistically significant difference between the groups. 1 Independent samples t-test 2 Pearson chi-square 3 ANCOVA Abbreviations: SD; standard deviations, AI; acromial index, AHM;, LAA; lateral acromion angle, CSA; critical shoulder angle, 95% CI; 95% confidence interval, RCT; rotator cuff tear partial thickness tear compared to healthy controls (adj. p<.001) (**Graphic 1-A**). There was a significant difference in AHM values between the study groups (F2,83=41.71, p<.001, η2=0.50). Post-hoc analysis, which is performed with a Bonferroni adjustment, showed that the AHM values in patients with full thickness tear was (5.33, 95% CI:4.87-5.78) lower than patients with partial thickness tear (7.27, 95% CI: 6.88-7.66, adj. p<.001) and healthy controls (8.49, 95% CI: 8.06-8.92, adj. p<.001). In addition, the AHM values were significantly lower in patients with partial thickness tear compared to healthy controls (adj. p<.001) (**Graphic 1-B**). There was a significant difference in LAA values between the study groups (F2,83=17.53, p<.001, η2=0.30). Post-hoc analysis, which is performed with a Bonferroni adjustment, showed that the LAA values in patients with full thickness tear (68.65, 95% CI:66.53-70.77) and in patients with partial thickness tear were (70.46, 95% CI: 68.62-72.30) lower than healthy controls (77.24, 95% CI: 75.22-79.25, all adj. p<.001). However, the LAA values were similar in patients with full thickness tear and partial thickness tear (adj. p=.653) (**Graphic 1-C**). There was a significant difference in CSA values between the study groups (F2,83=22.44, p<.001, η2=0.35). Post-hoc analysis, which is performed with a Bonferroni adjustment, showed that the CSA values in patients with full thickness tear was (35.68, 95% CI:34.81-36.55) higher than patients with partial thickness tear (33.91, 95% CI: 33.16-34.67, adj. p=.012) and healthy controls (31.31, 95% CI: 30.48-32.14, adj. p<.001). In addition, the CSA values were significantly higher in patients with partial thickness tear compared to healthy controls (adj. p<.001) (**Graphic 1-D**).

The diagnostic performance of AI, CSA, AHM, and LAA to differentiate RCT patients from healthy controls were given in **Table 4** and **Graphic 2**. The cut-off values for discriminating the RCT and healthy controls were as follows: AI>0.61, AHM≤7.1, LAA≤72 and CSA>32.7. The area under the curve (AUC) was 0.885 (95% CI, 0.799-0.944) with 81% of sensitivity, 83% of specificity, 90% of PPV, and 69% of NPV for the AI, 0.894 (95% CI, 0.809-0.950) with 74% of sensitivity, 93% of specificity, 96% of PPV, and 64% of NPV for the AHM, 0.857 (95% CI, 0.765-0.923) with 71% of sensitivity, 90% of specificity, 93% of PPV, and 61% of NPV for the LAA, and 0.888 (95% CI, 0.802-0.945) with 85% of sensitivity, 80% of specificity, 89% of PPV, and 72% of NPV for the CSA.

Table 3. The comparisons of demographical characteristics and acromial measurements in healthy controls and RCT patient groups

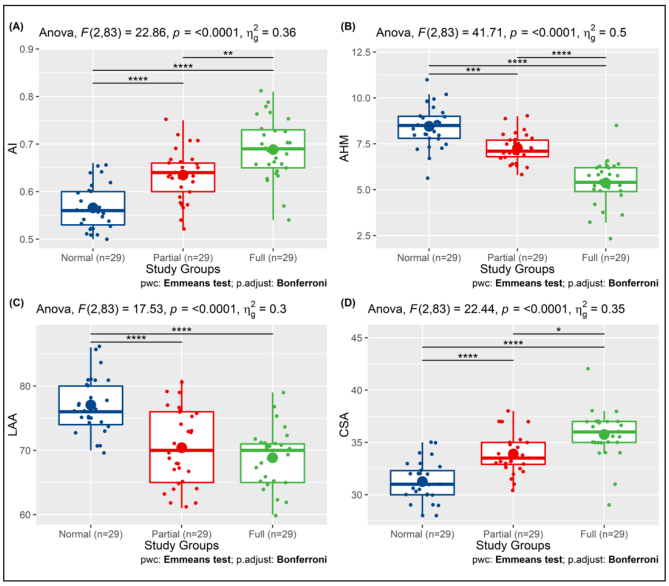
		RCT patients		
	Heathy controls (n=29)	**Partial thickness (n=29)**	**Full thickness (n=29)**	**p value**
Age (years)	44.14±13.11[a]	50.79±10.45[a]	64.38±9.68[b]	<.001[1]
Gender (F/M)	12/17	13/16	18/11	.240[2]
Acromial shapes				.031[2]
Type I (flat)	9 (31)	10 (34.5)	6 (20.7)	
Type II (curved)	19 (65.5)	15 (51.7)	13 (44.8)	
Type III (hooked)	1 (3.4)[a]	4 (13.8)	10 (34.5)[b]	
AI				
Mean±SD	0.57±0.05[a]	0.63±0.05[b]	0.69±0.06[c]	<.001[1]
Est. mean (95% CI)	0.57 (0.54-0.59)[a]	0.63 (0.61-0.66)[b]	0.69 (0.66-0.71)[c]	<.001[4]
AHM (mm)				
Mean±SD	8.45±1.13[a]	7.26±0.78[b]	5.37±1.19[c]	<.001[1]
Est. mean (95% CI)	8.49 (8.06-8.92)[a]	7.27 (6.88-7.66)[b]	5.33 (4.87-5.78)[c]	<.001[4]
LAA°				
Mean±SD	77.07±4.20[a]	70.41±5.88[b]	68.86±4.50[b]	<.001[3]
Est. mean (95% CI)	77.24 (75.22-79.25)[a]	70.46 (68.62-72.30[b]	68.65 (66.53-70.77)[b]	<.001[4]
CSA°				
Mean±SD	31.25±1.88[a]	33.90±1.92[b]	35.76±2.25[c]	<.001[1]
Est. mean (95% CI)	31.31 (30.48-32.14)[a]	33.91 (33.16-34.67)[b]	35.68 (34.81-36.55)[c]	<.001[4]

Data were presented as mean±standard deviation (range) and estimated mean with 95% confidence intervals, and also were described as count (n) and percentage (%). Bold values denote that statistically significant difference between the groups. Different superscript small letters in each row shows statistically significant difference between the groups after pairwise comparison tests. 1 One-Way ANOVA 2 Pearson chi-square 3 Welch's F test 4 ANCOVA Abbreviations: SD; standard deviations, AI; acromial index, AHM;, LAA; lateral acromion angle, CSA; critical shoulder angle, 95% CI; 95% confidence interval, RCT; rotator cuff tear, Est. mean; estimated mean, F; female, M; male

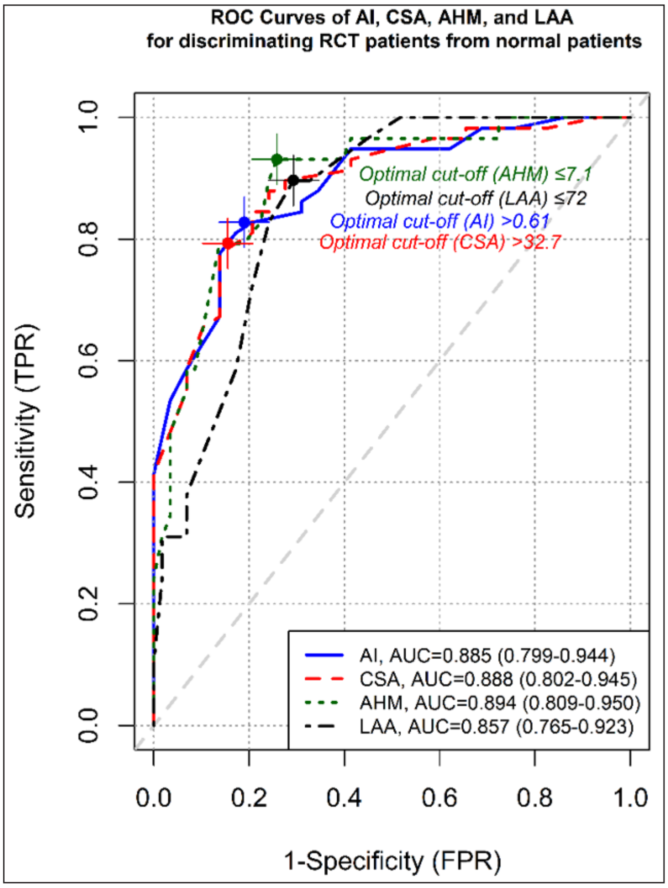
Table 4. Diagnostic performance of the AI, AHM, LAA, and CSA in diagnosis of RCT

	ROC curve analysis				Statistical diagnostic measures, (95% CI)			
	AUC (95% CI)	**p-value**	**Cut-off**	**J**	**Sensitivity**	**Specificity**	**PPV**	**NPV**
AI	0.885 (0.799-0.944)	<.001	>0.61	0.638	81 (69-90)	83 (64-94)	90 (81-96)	69 (56-79)
AHM	0.894 (0.809-0.950)	<.001	≤7.1	0.672	74 (61-85)	93 (77-99)	96 (85-99)	64 (54-74)
LAA	0.857 (0.765-0.923)	<.001	≤72	0.603	71 (57-82)	90 (73-98)	93 (82-98)	61 (50-70)
CSA	0.888 (0.802-0.945)	<.001	>32.7	0.638	85 (73-93)	80 (60-92)	89 (80-94)	72 (58-83)

Abbreviations: AI; acromial index, AHM;, LAA; lateral acromion angle, CSA; critical shoulder angle, AUC (95% CI); area under the curve (95% confidence interval), ROC; receiver operating characteristic curve, J; Youden J index, PPV; positive predictive value, NPV; negative predictive value



Graphic 1. Box-plots of AI, AHM, LAA, and CSA in patients with RCT and healthy controls. (A) the level of AI in study groups



Graphic 2. Receiver operating characteristics (ROC) curve analysis of the diagnostic performance of AI, CSA, AHM, and LAA

DISCUSSION

Anatomical variations of the acromion may be a predisposing factor for RCT by causing changes in the resultant of vector forces. The extent to which the anatomical factors play a role in RCT is not fully known (1). MRI provide us to evaluated the status of the rotator cuff and the shape of the acromion. Hamid et al. reported that classification for acromial morphology is unreliable and operator dependent. AI is not significantly associated with RCTs but increased AI is related to shoulder pain (11). In another study, they argued that the reason why the relationship between acromion shape and RCT is not fully established in the literature is that it is affected too much by interobserver variability during the evaluation of acromine classification. And they argued from the same study that the shape of acromine should be considered 3-dimensional (12). Thus, it was revealed that bone spurs at the anterior and lateral edges of the acromion lead to RCT (12). In our study we found that there was a significantly association between study groups and Type III (hooked) of acromial shapes, Type III proportion of acromial shapes was significantly higher in RCT patients than in healthy controls. Hirano et al. reported that the size of rotator cuff tears in type III acromions was significantly larger (13), which was consistent with our results. In several studies, they found that the type III acromion was the most frequently seen in patients with RCT (12,14). Nicholson et al. (15) revealed that while one of the most important causes of RCTs is increased age, it is seen that the acromial shape is an age-independent anatomical structure. They also argued that changes such as bone spur within the acromion develop over time as a result of RCT rather than the cause of RCT. Unlike many studies, Almokhtar et al. (16) found that a flat acromion is the most frequently seen type among all patients with RCTs.

AI provides the evaluation of the morphology of the acromion and compared the lateral extension of the acromion. Many studies suggested that AI was significantly higher in patients with RCT and AI as a reliable predictor of a rotator cuff tear (17). Kum et al. (17) suggested that AI was an effective predictive factor for RCT in a Korean population while other researchers suggested that AI might be changed according to race. Our study showed that the AI values in patients with full thickness tear was higher than patients with partial thickness tear. In addition, the AI values were significantly higher in patients with partial thickness tear compared to healthy controls. In another study, reported that AI is a useful measurement in distinguishing a partial-thickness articular-side tear and a large-to-massive rotator cuff tear pre-operatively. But the AI can not estimate the tear size in full-thickness tear patients (18).

Another anatomical variation that leads to large and massive RCT is reduced AHD and increased CSA. The AHD <6 mm and CSA >35° is usefulin predicting RCT. However, the AHD <6 mm, an acquired pathology as a result of RCT. With weakening of the rotator cuff muscle, the humeral head subluxes superiorly, resulting in narrowing of the AHD (19). The joint shear and joint compression forces are in the balanced within the joint. The enlarged CSA is deteriorate the compensatory effect of the supraspinatus tendon (20). In our study, AHD values in patients with full thickness tear was lower than patients with partial thickness tear and healthy controls. In addition, the AHM values were significantly lower in patients with partial thickness tear compared to healthy controls. While it is stated in the literature that AHD <7 mm may cause poor outcome after RCT repair, it has been stated that repair of the infraspinatus rupture is most likely not possible when AHD <4 mm. We found that the cut-off values for discriminating the RCT and healthy controls were as follows: AI >0.61, AHM ≤7.1, LAA ≤72 and CSA >32.7. Narrowed AHD lead to the fatty degeneration of the infraspinatus (21). Saupe et al. (22) suggested that AHD measurement is not affected from the inter and itraobservervariability, and they also suggested that AHD is an effective measurement in predicting RCT on both radiograph and MRI. However, in another study emphasize that there is a significant difference in AHD measurements between radiograph and MRI and should not be used interchangeably (23). Many of the studies suggested AHD is useful in predicting RCT, but literature still remain controversary on which imaging modality more reliable (21-23).

CSA is one of the important biomechanical measurement which is highly affected the shoulder abduction, glenoid compression, and joint shear forces. It is a delicate measurement and may interfere with different positioning of the scapula and acromion (24). Measured CSA on radiograph can estimate the necessity of preoperative MRI in the evaluation of the rotator cuff. As the CSA increased, number of tendons torn and anchors used for repair is increased (24). The CSA >35° may alter deltoid vectors and cause increased superior shear forces on the rotator cuff muscles. Increased shear forces may predispose for the RCT. The CSA <30° is related to osteo arthritis by the mechanism of the increased compressive forces across the glenohumeral joint (25). In our study CSA values in patients with full thickness tear was higher than patients with partial thickness tear and healthy controls. LAA reflect the inclination of the inferior surface of the acromion proportionate to the glenoid plane.of scapula (1). LAA is helpful measurement in understanding the shape of the acromion and its association with RCT. Decreased LAA might be related to RCT. Recently in a study found that acromial thickness, AHD, AI and LAA, were significantly different in patients with type-III acromial shape and RCT (1). Guishan et al. (25) defined these morphological variations of the acromion as "congenital and osteal etiological Factors" for RCT. We also found that LAA values in patients with full thickness tear and in patients with partial thickness tear were lower than healthy controls.

Our study has some limitations. First, the mean age of the patients with RCT and the control group were different from each other, and the different results that would arise from this were not taken into consideration. Another limitation of our study is that it was not conducted prospectively and only a small number of patients were examined.

CONCLUSION

Type III (hooked) of acromial shapes, higher AI and CSA values, lower AHD and LAA values are more frequently seen in RCT patients, in our study. Thus, we revealed anatomical malformations that predispose to RCT concerning the shoulder joint.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study was carried out with the permission of Tokat Gaziosmanpaşa University Hospital, Non-invasive Clinical Researches Ethics Committee (Date: 20.01.2022, Decision No: 2022/02).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

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Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper and that they have approved the final version

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