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ORIGINAL PAPER
PŮVODNÍ PRÁCE

The Impact of Coracoid Tip Orientation on Subscapularis Tear Incidence: an MRI-Based Study

Vliv orientace hrotu korakoidu na výskyt trhlin šlachy m. subscapularis: studie založená na MRI

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ABSTRACT

PURPOSE OF THE STUDY

This study investigated the relationship between the position of the tip of the coracoid process (CP) relative to the glenoid with subscapularis (Ssc) tears. We hypothesized that the coracoid tip is more inferior, lateral and posterior in patients with Ssc tear.

MATERIAL AND METHODS

This research enrolled 34 isolated Ssc tears and 44 controls. We introduced the axial central glenoid-coracoid angle (acGCA) and sagittal central glenoid-coracoid angle (scGCA) to evaluate the position of the tip of the CP relative to the glenoid center on MRI images. In both groups, acGCA, scGCA on MRI and critical shoulder angle (CSA), glenoid inclination (GI) on true anterior-posterior shoulder radiography were evaluated.

RESULTS

When both groups were compared in terms of acGCA, the acGCA values of the Ssc tear group were significantly higher than the control group (p<0.001). The best cut-off value of acGCA for Ssc tears was 28.3°. acGCA values higher than 28.3° showed 93.3% sensitivity and 93.1% specificity for Ssc tears (likelihood ratio:13.53, AUC: 0.979, 95% CI of AUC: 0.950–0.999). In terms of acGCA, the power analysis between Ssc tears group and control group was 99.9% between Ssc tears and the control group (effect size d=2.63). When both groups were compared in terms of scGCA, the scGCA values of the Ssc tear group were significantly higher than the control group (p<0.001). The best cut-off value of scGCA for Ssc tears was 41.4°. Scores of scGCA greater than 41.8° showed 80% sensitivity and 89.7% specificity for Ssc tears (likelihood ratio: 7.73, AUC: 0.899 95% CI of AUC: 0.837–0.958). In terms of scGCA, the power analysis between Ssc tear and control group was 99.8% (effect size d=1.23). When both groups were compared in terms of CSA and GI; CSA and GI values in the Ssc tear group were significantly higher (p<0.001 and p<0.012, respectively).

CONCLUSIONS

AcGCA values higher than 28.3° indicate that the coracoid tip is located more laterally and posteriorly; scGCA values higher than 41.8° indicate that the coracoid tip is located more inferiorly and these two new indexes are showing that more laterally, posteriorly and inferiorly coracoid tip is related to subscapularis tears.

Key words: coracoid process, subscapularis tear, coracoid morphology, scapula morphology.

INTRODUCTION

Rotator cuff tears are a common disability, especially in the elderly population (16, 18). 31–37% of repaired rotator cuff tendons are subscapularis (Ssc) tears (5, 13). Ssc tears are linked to a coracohumeral distance (CHD) of <6 mm in the axial plane (8). Gerber et al. identified coracoid overlap, coracoglenoid angle, and subcoracoid compression as indicators of lateral coracoid overflow from the glenoid plane (6, 7). Tollemar et al. argued that CHD is unrelated to SSC tears (17). Most CHD studies measure the relative position of the coracoid and humeral head, but this distance may vary with the arm position (2). On the other hand, Leite et al. defined the coracoid angle and showed that the shape and length of the coracoid is associated with subscapularis tears (9). Few studies have investigated the relationship between scapular morphology and Ssc tears, and to our knowledge, no study has yet examined the relationship between the position of the coracoid apex relative to the glenoid and subscapularis tears from a holistic perspective (9, 17).

The aim of this study was to investigate the relationship between Ssc tears and the position of the coracoid tip relative to the center of the glenoid using the acGCA and scGCA parameters, which can assess the position of the coracoid apex in medial-lateral superior-inferior and anterior-posterior planes.

MATERIAL AND METHODS

This research has been approved by the IRB of the authors' affiliated institutions

Among the 495 patients who underwent shoulder arthroscopy in the Department of Orthopedics and Traumatology between 2018–2019, 34 had isolated Ssc tears (Lafosse type 2-4, Goutallier grade 1–3) were included. The exclusion criteria were 'os acromiale', shoulder instability, superior migration of the humeral head, scapular dyskinesia, subacromial spur, acromioclavicular joint arthrosis, previous upper-extremity surgery, and congenital malformation. The control group included 44 patients without any shoulder pathology on imaging or physical examination.

Shoulder magnetic resonance (MR) images of 78 patients, 43 males and 35 females, with a mean age of 50.3±12.4 (26–65) years, performed according to the standards, were retrospectively analyzed (demographic information is summarized in Table 1).

We defined the axial central glenoid-coracoid angle (acGCA), which evaluates the distance of the coracoid process tip anteriorly from the glenoid center in the axial plane and the amount of lateral overflow (coracoid overlap) relative to the glenoid articular surface plane (Fig. 1). Additionally, we defined the sagittal central glenoid-coracoid angle (scGCA), which evaluated the height of the coracoid process tip relative to the glenoid center in the sagittal plane and the anterior distance from the glenoid center (Fig. 2).

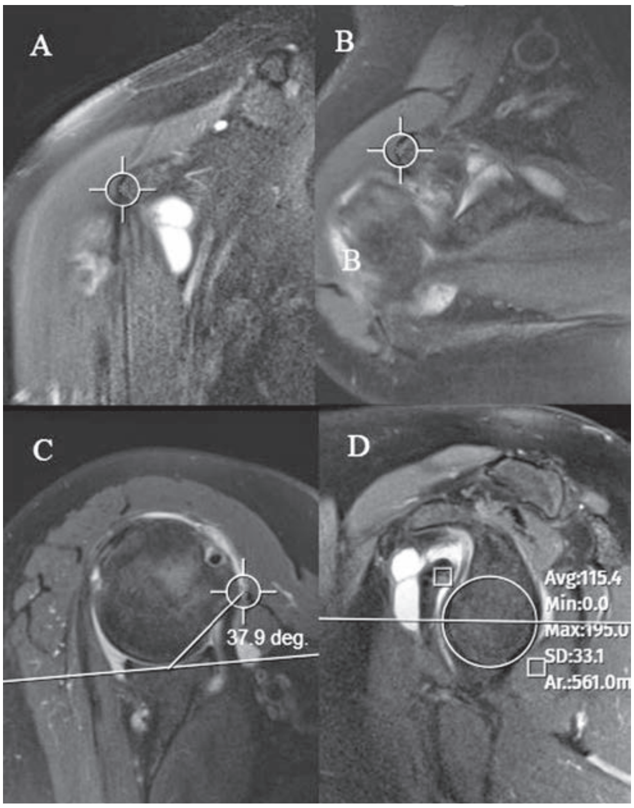

Fig. 1. Measurement of acGCA in a patient with ruptured Ssc. A and B: shows the most lateral point of the coracoid process in the coronal and axial planes, and these points are referenced to each other (the mark remains fixed and constant even if the sections are advanced). C: Projection of the mark in "B)" indicating the most lateral point of the coracoid process on the section through the center of the glenoid. acGCA is between the line passing from the projection of the tip of the coracoid to the center of the glenoid and the line passing through the glenoid articular surface line. D: The sagittal plane passing through the glenoid articular surface, referenced by "C."

Table 1. Demographic characteristics of patients

	Number of patients (n)	Age ± SD (min–max)	Sex (M/F)
Ssc tear group	34	55.9±6.6 (42–65)	18/16
Control group	44	51.1±10.6 (31–65)	25/19
P value		0.225	0.746

(Ssc: Subscapularis, M: Male, F: Female)

CSA is at the intersection between the line connecting the inferior and superior of the glenoid, and the line connecting the inferolateral of the acromion and the inferior of the glenoid. It has been related to common shoulder pathologies such as shoulder osteoarthritis and rotator cuff diseases (10, 11, 12) (Fig. 3). The β angle is at the intersection between the line passing through floor of the supraspinatus fossa and the line passing through the articular surface of the glenoid fossa. The glenoid inclination (GI) is the angle obtained by subtracting the β angle from 90°, with positive values portraying superior GI and negative values portraying inferior GI (10). It has been shown that GI described by Maurer et al. is associated with common pathologies such as rotator cuff disease and shoulder osteoarthritis (4, 10, 11, 12) (Fig. 4) .

acGCA, scGCA, GI, and CSI were measured by two different observers in two separate sessions, blinded to each other, in 77 patients with standard shoulder AP radiographs and shoulder MR imaging. After the reliability analysis, the mean of the four measurements was calculated. After statistical analysis, post-hoc power analysis was performed using G*Power version 3.1.9.4.

Data were analyzed with the SPSS software (IBM-SPSS 22.0). Descriptive statistics and frequency analysis were used to describe the data. The intra- and inter-class correlations between the measurements made by the same observer in separate sessions, as well as the measurements made by the two different observers were assessed by the intra-group correlation coefficient (ICC). Means and confidence intervals of the four measurements were entered into the computer. Normality assessment of the numerical data was done with the Shapiro-Wilk test. independent sample T-test, and Mann-Whitney U tests were used to compare independent variables, where $p<0.05$ were considered significant. Spearman's Rho and Pearson tests were used for correlation analysis between groups. Finally, the ROC analysis was utilized for sensitivity, specificity, and cut-off values.

RESULTS

The ICC was between 0.82 to 0.92 for all calculations, showing high within-observation reliability.

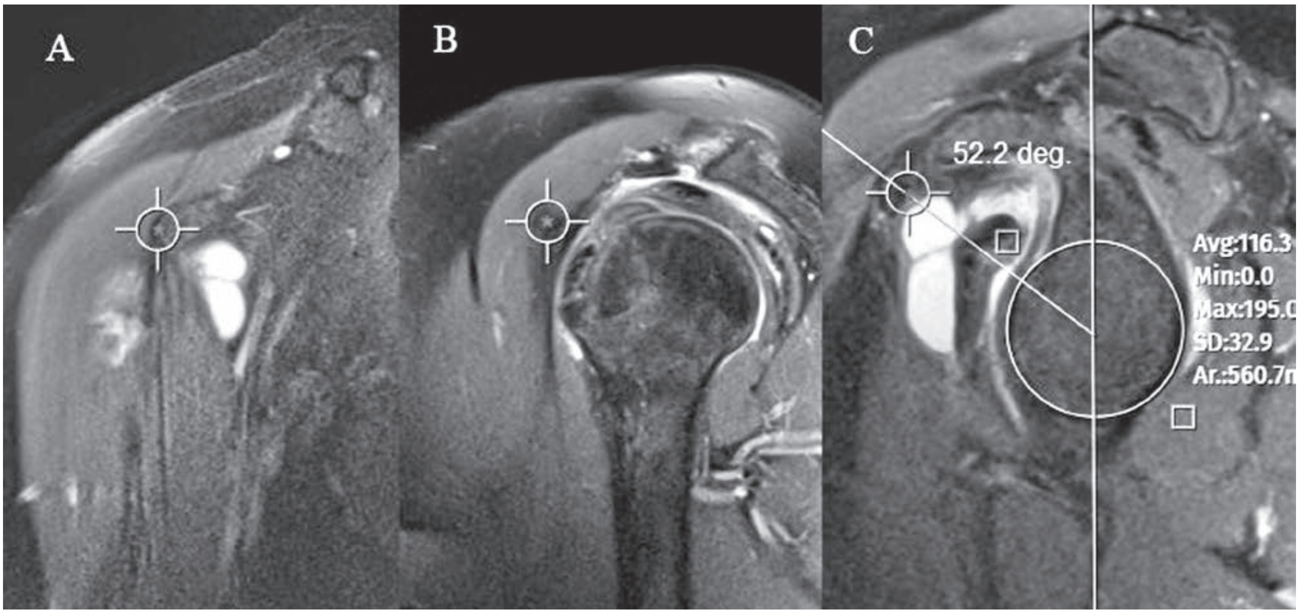

Fig. 2. Measurement of the scGCA in a patient with a ruptured Ssc. A and B: Shows the most lateral point of the coracoid process in the coronal and sagittal planes and are referenced to each other (the mark remains constant and fixed even if the slices are advanced in the sagittal plane). C: Projection of the marker for the most lateral point of the coracoid process shown in "B)" on the section through the glenoid articular surface. The glenoid articular surface is determined, and the center of the circle filling the glenoid and the vertical axis of the glenoid through the center of this circle are drawn. The scGCA is located between the line extending from the projection of the coracoid tip to the center of the glenoid and the glenoid vertical axis line.

When both groups were compared in terms of acGCA, the acGCA values of the Ssc tear group were significantly higher than the control group ($p<0.001$) (Tables 2 and 3). The best cut-off value of acGCA for Ssc tears was 28.3°. acGCA values higher than 28.3° showed 93.3% sensitivity and 93.1% specificity for Ssc tears (likelihood ratio:13.53, AUC: 0.979, 95% CI of AUC: 0.950–0.999) (Fig. 5, 6). In terms of acGCA, the power analysis between Ssc tears group and control group was 99.9% between Ssc tears and the control group (effect size d=2.63).

When both groups were compared in terms of scGCA, the scGCA values of the Ssc tear group were significantly higher than the control group ($p<0.001$) (Ta-

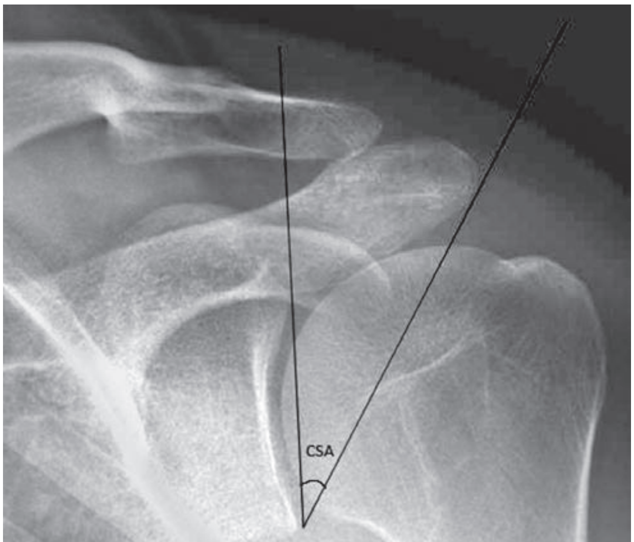

Fig. 3. X-ray showing the CSA measurement (angle between the line joining the inferior and superior of the glenoid and the line joining the inferolateral acromion and the inferior of the glenoid).

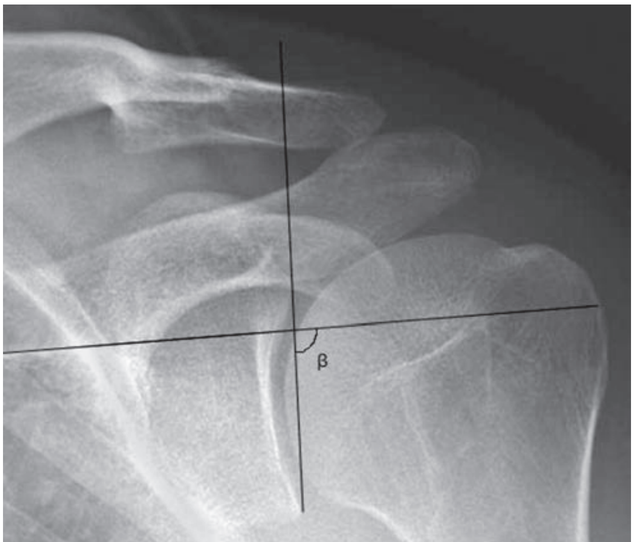

Fig. 4. X-ray showing the measurement of the β angle (the angle formed by the intersection of the line passing through the floor of the supraspinatus fossa and the line passing through the articular surface of the glenoid fossa).

Table 2. Mean acGCA, scGCA, CSA, and GI values

Group / Variable	Ssc tear group	Control group	p-value
Mean acGCA±SD (min–max) (95%CI)	35±5.1 28.1–46 32.2–37.9	21.8±5.8 11.5–33.2 18.5-25.2	<0.001
Mean scGCA±SD (min–max) (95%CI)	46.5±4.5 34.1–55.2 42.9–50.1	38.7±7 25.9–53 34.6–42.7	0.003
Mean CSA±SD (min-max) (95%CI)	42.5±2.7 37.7–49.9 41.1–44	34.7±2.4 33.4–42.9 35.3–38	<0.001
Mean GI±SD (min–max) (95%CI)	17.8±7.3 2.1–26.9 13.7–21.8	11.7±4.5 3.3–18.6 9.1–14.3	0.012

(acGCA: axial central glenoid-coracoid angle, scGCA: sagittal central glenoid--coracoid angle, CSA: critical shoulder angle, GI: glenoid inclination)

Table 3: Comparisons of patient groups regarding the studied measurements

Parameter	Variable	Value
acGCA	Mean difference±SD	13.2±2
	95% CI of mean difference	9 - 17.3
	Power (effect size d)	100% (2.63)
scGCA	Mean difference±SD	7.9±2.5
	95% CI of mean difference	2.7-13
	Power (effect size d)	99.8% (1.23)
CSA	Mean difference±SD	5.9±0.9
	95%CI of mean difference	3.9-7.8
	Power (effect size d)	100% (2.19)
GI	Mean difference±SD	6.1±2.3
	95% CI of mean difference	1.4 - 10.7
	Power (effect size d)	91.6% (0.83)

(acGCA: axial central glenoid-coracoid angle, scGCA: sagittal central glenoid-coracoid angle, CSA:critical shoulder angle, GI:glenoid inclination, SD:standart deviation, CI:confidence interval)

bles 2 and 3). The best cut-off value of scGCA for Ssc tears was 41.4°. Scores of scGCA greater than 41.8° showed 80% sensitivity and 89.7% specificity for Ssc tears (likelihood ratio:7.73, AUC:0.899 95% CI of AUC: 0.837–0.958) (Fig. 5, 6). In terms of scGCA, the power analysis between Ssc tear and control group was 99.8% (effect size d=1.23).

Furthermore, when both groups were compared in terms of CSA values, the CSA values of the Ssc tear group were significantly higher than the control group (p<0.001) (Tables 2 and 3) Finally, when both groups were compared in terms of GI, the GI values of the Ssc tear group were significantly higher than the control group (p<0.001) (Tables 2 and 3).

acGCA and CSA had a significant and strong relation (p<0.001, r=0.64). Moreover, scGCA and glenoid inclination had a significant and moderate-strong rela-

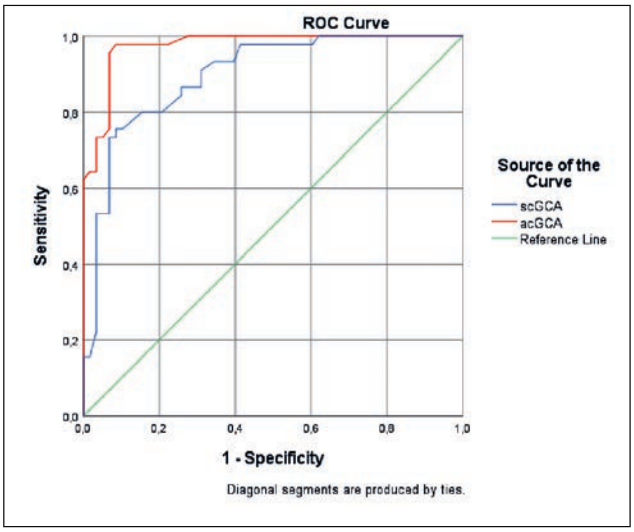

Fig. 5. Graph showing the ROC curves of acGCA and scGCA

tion (p=0.048, r=0.47). Finally, acGCA and scGCA were significantly correlated, with a moderate correlation (p=0.002, r=0.46).

DISCUSSION

The key finding of this study is that the location of the CP tip that is inferior, lateral, and posterior is related to Ssc tears. The acGCA higher than 28.3°, indicating that the CP was lateral and posterior, were related to Ssc tears with a sensitivity of 93.3% and a specificity of 93.1%, and scGCA higher than 41.8° indicated that the CP was inferior and was related to Ssc tears with 80% sensitivity and 89.7% specificity.

Leite et al. defined the coracoid angle and showed that the shape and length of the coracoid is associated with subscapularis tears (9). The coracoid angle (CA) was the angle between the proximal and distal segments of the coracoid in the sagittal section where it was best visualized, and this angle did not provide any information about the relationship between the coracoid and the glenoid. In their study, they classified the coracoid morphology according to the coracoid angle they defined

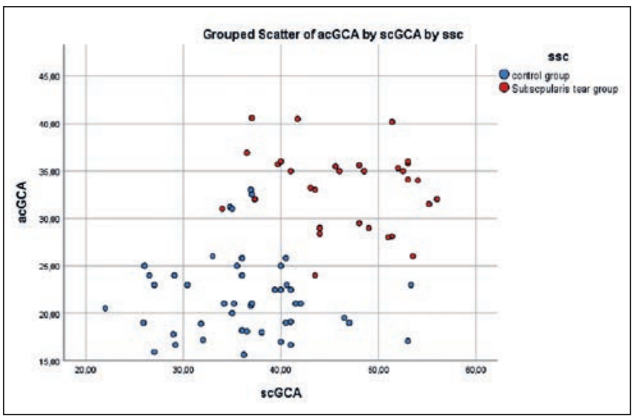

Fig. 6. Graph showing the distribution of acGCA and scGCA values in the ssc tear group and control group patients.

and divided it into three as flat coracoid if CA>120°, curved coracoid if CA 95–120° and hooked coracoid if CA<95°. The two studies support each other in that the increased scGCA in our study showed a coracoid apex located in a more inferior position and the coracoid in the hook type in the study of Leite et al. was directed inferiorly and in both cases the risk of Ssc tear increased. As the coracoid angle decreases, it can be thought that the coracoid is directed inferiorly and turns into a hook type, but this angle cannot directly give an idea about the position of the coracoid apex relative to the center of the glenoid. Considering the function of the healthy functioning rotator cuff muscles to centralize the humeral head at the glenoid center, we thought that the glenoid center is the point of reference when investigating the relationship between coracoid and subscapularis tear. It may be an advantage that acGCA and scGCA provide measurable data with high sensitivity and specificity to provide information about the risk of Ssc tear, regardless of and unaffected by coracoid type.

The coracoglenoid angle was defined by Gerber et al. as the angle intersecting the line passing through the glenoid articular surface in the axial plane and the line passing through the anterior glenoid corner and the lateral coracoid process (6, 8, 18). They showed a correlation between small coracoglenoid angle values and subcoracoid impingement. The size of the glenoid in the axial section influences this measurement described by Gerber et al. Without changing the location of the coracoid in the axial section, the measured angle will increase as the glenoid size increases, and will decrease as the glenoid size decreases. Therefore, we think that it would be appropriate to take the glenoid center instead of the anterior corner as the reference point so that the angle measurement, which evaluates the coracoid's relative position to the glenoid in the axial plane, is not affected by the glenoid size. Coracoid impingement and Hawkins Kennedy provocative tests are diagnostic tests based on creating an impingement by reducing the distance between Ssc insertion and CP with adduction, internal rotation, and forward flexion movements. It has been shown that decreasing the distance between the SSC insertion and the CP causes subcoracoid compression by causing repetitive microtraumas (14). Considering that the rotator cuff muscles try to keep the humeral head in a single rotation center during shoulder movements, in patients with high acGCA (i.e., in cases where the location of CP is posterior and lateral) it can be thought that the natural gap between the CP and Ssc tendon insertion will be less, and this may increase the risk of subcoracoid impingement and Ssc tear.

In their study, Çetinkaya et al. found that coracoid overlap in the axial plane was significantly increased in patients with subscapularis tear (3). In the same study, they measured the anterior distance of the coracoid from the glenoid to the anterior border of the glenoid in the cross-section, where the glenoid articular surface was visible in the sagittal plane, and no significant results were found. Increased coracoid overlap and acGCA are associated with SSC tears supporting each other. However, while coracoid overlap alone provides an idea of only lateral extension, acGCA can also provide an opinion about the anterior extension of the CP. The reason why the measurement of the anterior extension of the coracoid in this study by Çetinkaya et al. could not find a significant relationship with Ssc tear may be due to the glenoid anterior border being the reference point because it can affect glenoid size measurements, and the section in which the CP appears best may not be the section where the glenoid appears the widest. The increased acGCA may be a new measurement showing that the CP is more posterior and lateral, thus reducing the natural space between itself and the Ssc tendon in two different planes.

Watson et al. defined the sagittal coracoglenoid angle between the line starting at the middle of the sagittal plane coracoid base and extending to its inferior of the coracoid where the glenoid articular surface is seen and the line intersecting the anterior rim of the glenoid; they found a significant relationship with Ssc tears (18). A significant relationship was found in patients with scGCA subscapularis tears that we described in our study. This study by Watson et al. supports our work in showing that the coracoid process is inferior in patients with Ssc tear than in normal patients. In patients with a high scGCA angle and, therefore, a more inferior CP, the distance between the Ssc insertion and the CP probably decreases earlier during forward flexion, causing earlier impingement; therefore, more compression and more microtrauma-induced Ssc tears occur. When acGCA and scGCA, which have a significant positive correlation with each other, are evaluated together, it shows that CP is both more inferior, more lateral, and posterior in the group with Ssc tear, and this position of CP is probably the position where the distance between Ssc insertion and CP is the least. Watson et al.'s study and our study differ in evaluating the coracoid in the sagittal plane. The first of these differences is that in our study, the projection of the most lateral point of the coracoid in the sagittal plane, in the section where the glenoid is visible, was taken as reference while the study of Watson et al. measured the coracoid in the section where the glenoid is visible, not the most lateral point of the coracoid. We think it is more consistent to make measurements based on the coracoid's tip in measurements related to the sagittal plane, as in the measurements made in the axial plane in Ssc tears. The second difference is that Watson et al.'s study was based on the anterior of the glenoid, but our study was based on the center of the glenoid, therefore, we think that the scGCA measurement may be more reliable, since it is not affected by the glenoid radius.

In our study, a significant positive correlation was observed between CSA and acGCA, which means that the amount of lateralization of the acromion and coracoid concerning the glenoid plane is correlated. The conclusion that can be drawn here is that CSA, which is related to with many chronic pathologies, may not only be associated with the glenoid and acromion, but also with the coracoid. A significant positive correlation was also obtained between GI and scGCA, which means that the amount of inferiorly facing glenoid and the amount of the inferior location of CP correlate. Furthermore, a significant positive correlation was obtained between acGCA and scGCA. In increasing acGCA values, the coracoid is positioned more laterally, and in increasing scGCA values, the coracoid is positioned relatively inferior. This situation was associated with Ssc tears in our study. In the study of Watson et al., these two studies support each other in associating Ssc tears with the coracoid located more laterally and inferiorly (18). The conclusion that can be drawn from this is that the coracoid, acromion, and glenoid may be more related than currently known

In the study by Park et al. they demonstrated that in patients with subacromial impingement syndrome, arthroscopic coracoplasty had better clinical outcomes (15). They especially showed that in patients who underwent coracoplasty there was significant improvement in internal rotation. Meanwhile Ayanoğlu et al. indicated that coracoplasty did not create a functional difference between isolated Ssc tear patients and those in the control group (1). In both studies the inclusion criteria was CHD. However, previous studies have shown that CHD is liable to change depending on the arm's position. In a nutshell, there is no consensus regarding the necessity of coracoplasty. In deciding necessity of coracoplasty, use of acGCA and scGCA in the place of CHD could produce more accurate outcomes. But to understand this better, further studies would need to be carried out.

Even though power and ROC analyses show that sample sizes are sufficient, the relatively low patient count caused by the broad exclusion criteria is a limitation. The control group consisting of patients with typical radiological images, having full shoulder function on examination, and nonspecific shoulder pain without a specified shoulder pathology can be considered a limitation as well. A final limitation is the study being retrospective despite the prospective data collection. Further 3D angle and distance measurements can more clearly reveal the relationship between scapular anatomy and shoulder pathologies.

CONCLUSIONS

The acGCA higher than 28.3° indicate that the coracoid tip is located more laterally and posteriorly; the scGCA higher than 41.8° indicate that the coracoid tip is located more inferiorly and these two new indexes are showing that more laterally, posteriorly and inferiorly coracoid tip is related to subscapularis tears.

Ethical approval: *Ethical approval was obtained from "Necmettin Erbakan University Ethical Committee"(Ref no: 2022-3570).*

Informed consent: *Informed consent was obtained from all patients that their radiological images would be used for scientific purposes in accordance with the decision of the university ethics committee.*

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