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Coracoid morphology and humeral version as risk factors for subscapularis tears

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Background: The pathophysiology of subscapularis (SS) lesions is still relatively unknown despite recent interest in predictive factors for SS tears. Our goal was to determine the influence of the coracoid morphology and humeral version on SS tears.
Methods: This was a retrospective, controlled, single-blinded study. We analyzed 232 shoulders with SS lesions confirmed by magnetic resonance imaging. The coracoid proximal length, coracoid distal length (CLD), and coracoid total length were measured. The coracoid length ratio, coracoid angle (CA), and humeral version were also evaluated.
Results: We found that greater humeral retroversion was progressively related to more serious SS injuries, with values of –28.6° ± 19.5° and –51.0° ± 11.1° in the normal SS group and tear group, respectively ($P < .001$). The same tendency was shown for the CA, with values of 123.8° ± 11.1° in the control group vs. 97.4° ± 10.1° in the tear group ($P < .001$). Greater CLD, coracoid total length, and coracoid length ratio were also associated with an increased risk of SS tears ($P < .001$). The CA and CLD represented the best predictors of SS tears, presenting areas under the receiver operating characteristic curve of 90.0% and 89.0%, respectively.
Conclusions: This article is the first to study the influence of different parameters of the coracoid process morphology and humeral version on SS tears. We proved that humeral version and coracoid morphology were important risk factors for SS pathology and could accurately predict these lesions. Finally, our study was the first to create a classification system to divide coracoids according to their morphology and relative risk of associated SS tears.
Level of evidence: Level III; Cross-Sectional Design; Epidemiology Study

Keywords: Subscapularis; rotator cuff tears; coracoid morphology; coracoid length; coracoid angle; humeral version; subcoracoid impingement

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The pathophysiology of rotator cuff tears remains controversial, with some authors advocating a degenerative process driven by hypoxia and overuse but other authors arguing that shoulder girdle morphology plays a predominant role.[5] Rotator cuff injuries have multifactorial causes, and many anatomic factors are implied. Neer[13] showed that most rotator cuff injuries, namely supraspinatus tears, result from impingement under the anterior acromion. A few years later, Bigliani et al.[2] proved that acromial morphology also influences the risk of rotator cuff tears.

Institutional review board approval was not required for this study.

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The coracoacromial arch and the coracoid are being recognized as major players in rotator cuff tears, with Gerber et al[8] describing the subcoracoid space and, later the coracoid overlap index.[9] However, studies focusing exclusively on the coracoid morphology and its influence on this pathology are lacking. Other authors, such as Tetreault et al[15] and Chalmers et al,[5] described the influence of glenoid inclination and version on rotator cuff tears, with superior inclination being regarded as a risk factor for rotator cuff pathology, and greater retroversion being predictive of anterior cuff injury and greater anteversion of posterior cuff lesions.[5,15]

Although the influence of the glenoid and coracoacromial arch on rotator cuff pathology is well established, no studies have focused on the influence of humeral version on rotator cuff pathology. Moreover, only a modest number of studies have been performed regarding the influence between coracoid morphology and rotator cuff injuries.[8,9,11] This is particularly true regarding subscapularis (SS) tears, of which the pathophysiology and risk factors are still very much unknown.

We know from our previous study that subcoracoid impingement can lead to SS tears and that smaller coracohumeral distances and greater coracoid overlaps are associated with a greater risk of anterior cuff pathology.[11] However, there is still uncertainty regarding the influence of the coracoid morphology on SS tears.

Humeral version, on the other side, is a well-established factor in shoulder instability; however, its influence on rotator cuff tears has never been studied. Studies evaluating humeral version initially used cadaveric models and radiographs,[14] later evolving to imaging studies with computed tomography (CT) that nowadays is widely used.[4,12] However, several authors have recognized that evaluating humeral version with CT has several disadvantages, such as exposure to ionizing radiation, as well as difficulty in defining the true limits of the articular cartilage and, as a consequence, low accuracy defining the central axis of the humeral head.[4,7] As a result, recent studies have preferred magnetic resonance imaging (MRI) to evaluate the shoulder girdle anatomy, particularly humeral version.[4,5] Most studies regarding humeral version have also used the transepicondylar axis as a reference, demanding images of the whole arm and consequently implying greater economic costs and radiation exposure. However, as most of the humeral head version is the result of torsion occurring in the proximal growth plate, this can be dismissed, and humeral version can be assessed using only images of the proximal humerus.[1,6]

The main goal of this study was to evaluate the influence of coracoid morphology on the incidence of SS tears, as well as determine the relationship between humeral version and SS injuries. We hypothesized that longer coracoids and inferior coracoid angles (CAs) would translate into an increased risk of SS lesions and that greater humeral retroversion would also be a risk factor for SS tears.

Materials and methods

We performed a retrospective, controlled, single-blinded study. Patient data were collected retrospectively from our institution's outpatient orthopedic clinical files and included all patients with SS pathology confirmed by MRI between 2009 and 2019. We excluded patients without an MRI study; obese patients (body mass index > 30); and patients with inflammatory arthropathy, rotator cuff arthropathy, shoulder instability, or congenital deformities.

The control group included patients observed at the orthopedic outpatient clinic for shoulder pain without rotator cuff pathology on the MRI study. The same exclusion criteria defined for the study group were applied.

Our institution's standard MRI shoulder protocol was applied, including T1- and T2-weighted fat-saturated images, with the patient in the supine position with the arm alongside the body, elbow extended, and forearm supinated. All MRI scans were performed in our institution's radiology department, using similar MRI models with equivalent gantries.

Coracoid morphology was evaluated, including (1) proximal segment length, (2) distal segment length, and (3) CA. Before measurement of the coracoid length was performed, the coracoid knee was defined by the intersection of the proximal and distal coracoid segments' long axes. The proximal coracoid segment was then defined between the coracoid base and its knee, and the distal segment, distal to it. Both lengths were evaluated on MRI axial sections (Fig. 1). The CA was measured using MRI sagittal cuts at the section corresponding to the greatest coracoid cross-sectional length. The proximal and distal coracoid segments' long

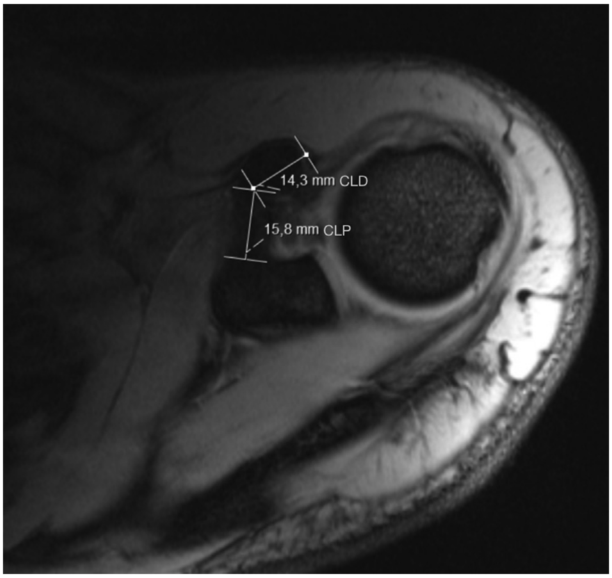

Figure 1 Evaluation of coracoid length including proximal and distal segment lengths. In this case, the coracoid proximal length *(CLP)* measured 15.8 mm and the coracoid distal length *(CLD)* measured 14.3 mm.

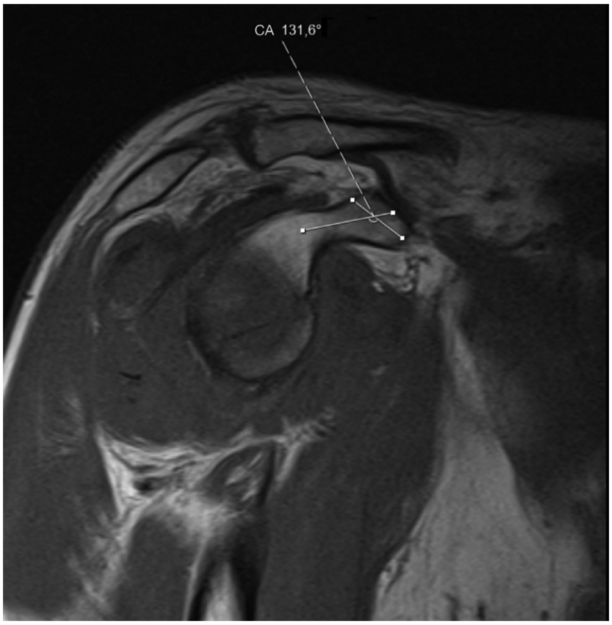

Figure 2 The coracoid angle *(CA)* was measured determining the angle between 2 lines passing at the axis of its proximal and distal segments.

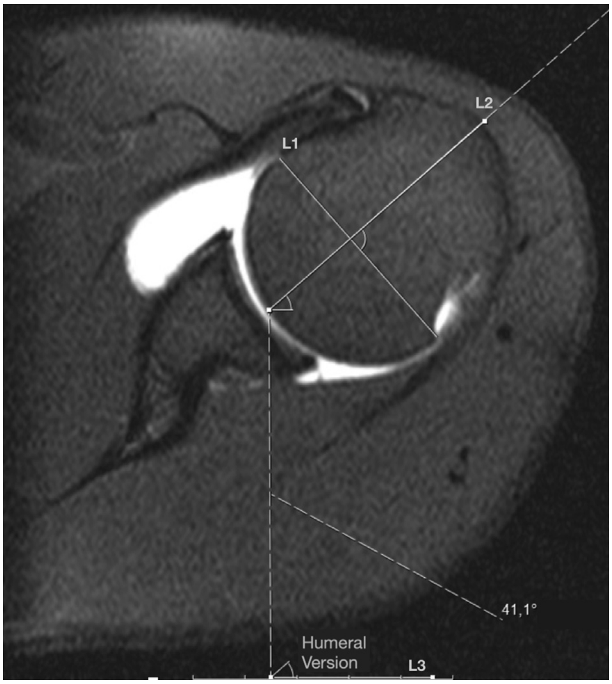

Figure 3 Humeral version, measured according to technique validated by Athwal et al,[1] using magnetic resonance imaging axial sections. The determined humeral version in this case was 41.1°. *L1*, line drawn between anterior and posterior limits of humeral head cartilage; *L2*, humeral head central axis, perpendicular to L1; *L3*, line parallel to magnetic resonance imaging scanner.

axes were traced, and the angle formed under these represented the CA (Fig. 2).

Humeral version was measured according to the technique validated by Athwal et al.[1] It is determined using MRI axial sections, first drawing a line (L1) joining the anterior and posterior margins of the articular cartilage, at the point of maximal head diameter, previously measured and defined. Thereafter, a perpendicular line (L2) passing at the L1 line midpoint was drawn. As such, L2 represented the central axis of the humeral head. A third line (L3) parallel to the MRI scanner orientation was drawn. Then, the angle drawn between L2 and L3 corresponded to humeral version. Retroversion was expressed in negative values; anteversion, in positive values (Fig. 3).

Both humeral version and coracoid morphology were measured using sections of T1-weighted images, taking advantage of the better definition of the cortical margins, and T2-weighted fat-saturated cuts, allowing the articular cartilage to be effectively evaluated. A standardized measurement technique was developed to determine humeral version, coracoid length, and CA. These measurements were recorded by the same orthopedic surgeon, blinded to the MRI report. The final recorded value represents the average of 3 separate and consecutive evaluations of each index. The presence of SS rupture, presence of long head of the biceps brachii (LHB) injuries, sex, and laterality were also recorded.

Statistical analysis

Statistical analysis was performed using SPSS software (version 24; IBM, Armonk, NY, USA). Categorical variables are presented as absolute and relative frequencies, whereas continuous variables are characterized by mean and standard deviations. The statistical tests used were the χ^2 test to evaluate the association between categorical variables and 1-way analysis of variance test to compare means of continuous variables. To determine the best cutoff points, receiver operating characteristic (ROC) curves were designed for each studied variable and the Youden index was applied. The value with the highest Youden index was considered the cutoff value with the best precision. $P < .05$ was considered statistically significant.

Results

The sample comprised 330 shoulders, including 129 female shoulders (39.1%) and 201 male shoulders (60.9%). The study group included 188 shoulders with SS tears and 44 shoulders with SS tendinopathy, corresponding to 70.3% of the sample. The control group included 98 shoulders without SS pathology, corresponding to 29.7% of the sample. Our series comprised 150 right (45.5%) and 180 left (54.5%) shoulders. Regarding the LHB, 29.1% of shoulders presented an LHB lesion (tear or subluxation).

No statistically significant relationship was found between the presence of an SS lesion and sex or laterality. Regarding simultaneous lesions, we found a significant association between SS lesions and LHB lesions ($P < .001$).

Table I Relationship between humeral version and SS lesions

SS status	n	Mean humeral version, °*
Normal SS	98	–28.6 ± 19.5
SS tendinopathy	44	–48.7 ± 9.1
SS tear	188	–51 ± 11.1

SS, subscapularis.
* $P < .001$.

The CA, coracoid proximal length (CLP), coracoid distal length (CLD), and humeral version were obtained from the 330-shoulder sample. Average humeral version was –44.1° ± 17.2° of retroversion. Regarding coracoid morphology, the average CA was 106.2° ± 15.4°. The coracoid length was divided into proximal (CLP) and distal (CLD) segments, with average values of 22.3 ± 3.7 mm and 10.2 ± 3.3 mm, respectively; the average coracoid total length (CLT) was 33.5 ± 5.2 mm. We postulated that a newly created coracoid length ratio (CLR), the ratio between the distal and proximal coracoid lengths, would help evaluate which of the coracoid segments had a greater influence on SS pathology; its average value was 0.43 ± 0.2.

Associating humeral version and the presence of an SS lesion, we found that greater retroversion had a statistically significant association with the presence of an SS tear ($P < .001$). Mean humeral version was –28.6° ± 19.5° in the control group, contrasting with –48.7° ± 9.1° in the SS tendinopathy group and –51.0° ± 11.1° in the SS tear group, with this difference being statistically significant between all groups ($P < .001$). In our series, as we reached greater humeral retroversion, a progression to more serious injuries of the SS occurred (Table I), with this difference being statistically significant ($P < .001$).

In addition, we found a significant relationship between greater humeral retroversion and increased frequency of LHB injuries, with mean humeral version of –39.4° ± 19.2° and –49.3° ± 12.3° in the group with normal LHB tendons and the injured LHB group, respectively ($P < .001$).

We also reached a statistically significant association between the measured coracoid indices and the presence of SS tears ($P < .001$). A greater CLD was associated with SS pathology, with average values of 6.8 ± 1.5 mm, 10 ± 2 mm, and 12.1 ± 2.7 mm for normal SS tendons, tendinopathy, and SS tears, respectively ($P < .001$). Similarly, the CLT was correlated with the presence of SS lesions: Healthy SS tendons were associated with a mean total length of 29.6 ± 3.9 mm; SS tendinopathy, 32.3 ± 4.6 mm; and SS tears, 35.8 ± 4.6 mm ($P < .001$). Furthermore, the CLR showed a significant association with SS tears, with average values of 0.3 ± 0.1 for normal shoulders and 0.5 ± 0.1 for the SS tear group ($P < .001$) (Table II).

However, with the CLP, we did not achieve a linear association with SS lesions. In our sample, the CLP was, on average, 22.8 ± 3.2 mm in shoulders without SS pathology, 22.3 ± 3.5 mm in those with tendinopathy, and 23.7 ± 3.9 mm in those with SS tears. In contrast, the CA reached a statistically significant relationship with the presence of SS tears ($P < .001$), with average values of 123.8° ± 11.1°, 104.6° ± 6.8°, and 97.4° ± 10.1° for normal tendons, SS tendinopathy, and SS tears, respectively.

ROC curves were designed to evaluate the ability of humeral version and coracoid ratios to predict SS lesions. The accuracy of the model was measured by the area under the ROC curve (AUC), with an AUC of 100% representing a perfect test.

Humeral version was a good predictor of SS injury (AUC, 79.0%) (Fig. 4), with the cutoff value of –44.5° having a sensitivity of 76.6% and specificity of 70.4% for SS tears. The CLD was a very strong predictor of SS tears, with an AUC of 89.0%. Applying the CLD–SS tear ROC curve, we found that the value of 9.3 mm had a sensitivity of 81.0% and specificity of 85.6% for SS tears. In addition, the CLR was an extremely good predictor of SS tears, showing an AUC of 87.0%, with the cutoff value of 0.4 reaching a sensitivity of 81.7% and specificity of 83.0% for SS lesions. Furthermore, the CLT represented a good model for predicting SS tears, with an AUC of 81.0%.

The CA was the best predictor of SS tears, with an AUC of 90.0% (Fig. 5), making it excellent in predicting these lesions. On the basis of analysis of the CA ROC curve, it is possible to define the cutoff value of 105.5° with a sensitivity of 82.4% and specificity of 78.9% for SS tears.

Table II Relationships between coracoid indices and SS lesions

SS status	Mean coracoid index, mm*			
	CLP	CLD	CLT	CLR
Normal SS tendon	22.8 ± 3.2	6.8 ± 1.5	29.6 ± 3.9	0.3 ± 0.1
SS tendinopathy	22.3 ± 3.5	10.0 ± 2.0	32.3 ± 4.6	0.5 ± 0.1
SS tear	23.7 ± 3.9	12.1 ± 2.7	35.8 ± 4.6	0.5 ± 0.1

SS, subscapularis; *CLP*, coracoid proximal length; *CLD*, coracoid distal length; *CLT*, coracoid total length; *CLR*, coracoid length ratio.
* $P < .001$.

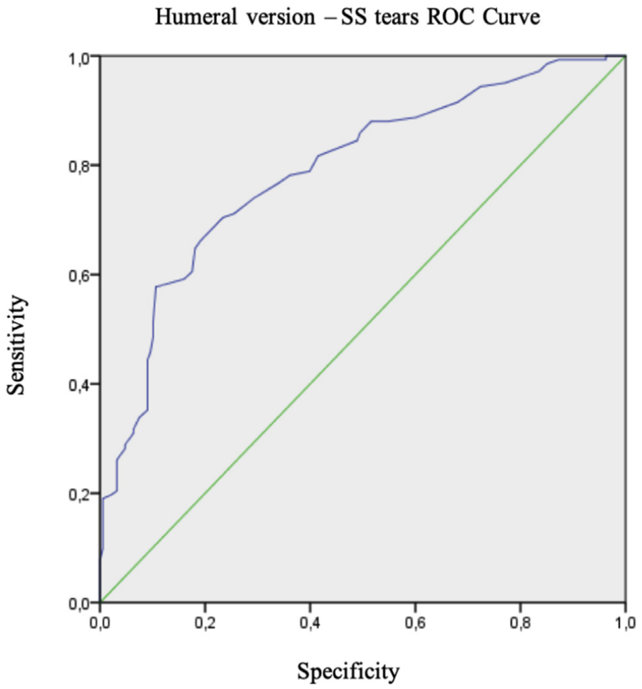

Figure 4 The humeral version receiver operating characteristic *(ROC)* curve showed it was a fair predictor of subscapularis *(SS)* injury (area under ROC curve, 79.0%).

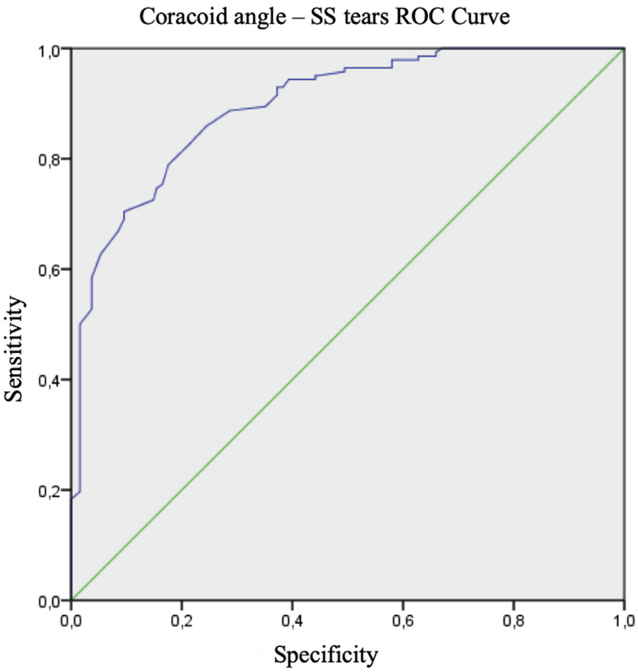

Figure 5 The coracoid angle receiver operating characteristic *(ROC)* curve showed it was an excellent predictor of subscapularis *(SS)* tears (area under ROC curve, 90.0%).

Discussion

The search for anatomic risk factors in rotator cuff pathology and possible SS tear predictors has been increasing in recent years. Many structures of the shoulder girdle have been implicated in these injuries, including the glenoid and acromion and, in the particular case of SS tears, the coracoid.

However, most studies evaluating the influence of the coracoid on SS tears have focused on the coracoacromial arch and coracohumeral distance, ignoring the influence of the coracoid shape and length. We chose to assess the coracoid lengths and CA to define which of these were most implicated in SS tears. Our results showed that both the coracoid length and the CA influence the risk of SS lesions but in different proportions. The CA was the index with the most predictive value for SS lesions (AUC, 90.0%), closely followed by the CLD (AUC, 89.0%) and CLR (AUC, 87.0%).

Even in comparison with other known SS risk factors, such as the coracohumeral distance or coracoid overlap, the CA proved to be a better predictor of SS lesions than coracoid overlap, with an AUC of 90.0% vs. 80.6%, and performed equivalently to the coracohumeral distance, with an AUC of 93% in some studies.[11] As the CA is an excellent predictor of SS tears, we used the CA ROC curve to define different risk categories in SS lesion development, according to the CA. These data allowed us to determine 3 types of coracoid morphology with an increasing risk of SS tears (Fig. 6): flat coracoid with CA superior to 120°, curved coracoid with CA between 95° and 120°, and hooked coracoid with CA inferior to 95°.

Using this coracoid morphologic classification system within our sample, we can see that the type I, or flat, coracoid presents a low risk of SS lesions, with only 4.5% of shoulders presenting SS tears. Regarding type II, or curved, coracoids, we can conclude that these are associated with an intermediate risk of SS lesions, with SS tears in 60.0% of these shoulders. Furthermore, type III, or hooked, coracoids are associated with a higher risk of SS injuries, with 97.2% of this group showing an SS tear (Table III).

To our knowledge, our study presents the largest sample on this topic, including 330 patients, being also the first to evaluate the differing influence of the CLP, CLD, and CLT length, as well as the CLR, on SS tears.

Our study showed that the distal coracoid length (AUC, 89.0%) is a more important determinant factor in SS tears than the proximal coracoid length (AUC, 57.0%) or total coracoid length (AUC, 81.0%). This finding can be explained by the coracoid anatomy, as the segment distal to the coracoid knee is directed inferiorly and laterally and therefore is in a closer relationship with the SS tendon compared with the proximal coracoid segment. In contrast, the CLP, with an AUC of 57.2%, is of no use in predicting SS lesions.

Our study is also the first to evaluate and prove that the CA is an excellent predictor of SS tears (AUC, 90.0%), showing that the angulation and shape of the coracoid

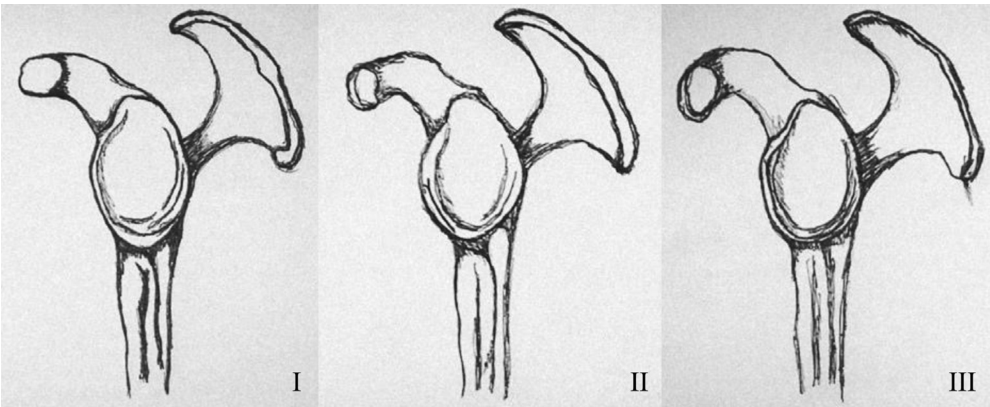

Figure 6 Leite-Torres classification of coracoid morphology: I, flat coracoid; II, curved coracoid; and III, hooked coracoid.

process are even more important than its size regarding SS tear pathology. In addition, our work was inaugural in using this parameter to create a classification system that allows us to divide coracoids by shape according to the relative risk of SS tears.

After it is determined that a patient is at higher risk of an SS lesion, on the basis of MRI measurements or our proposed classification, our results can translate into different approaches in the clinical setting. During arthroscopy, the surgeon should probably look for underdiagnosed SS lesions on preoperative MRI. If not found, he or she could eventually consider the choice of a “preventive” coracoplasty. In addition, during SS repair, in high-risk patients, the realization of performing a “protective” coracoplasty could also be considered to eventually diminish the chances of failure of the repair or rerupture. All these clinical repercussions need further studies with solid data that can back up eventual changes in clinical practice.

This study is the first to relate humeral version with SS tears. Analyzing the control group, we can see that average humeral version (–28.6° ± 19.5°) is within the range of values presented in the literature.[3,6,7,10,12] Furthermore, looking at the humeral version ROC curve, we can conclude that humeral version influences the incidence of SS tears and that greater humeral retroversion is linked to a greater risk of SS injury (AUC, 79.0%). This can be explained by the impingement of the articular surface of the SS tendon between the glenoid and more retroverted humerus, as theorized by Tétreault et al[15] regarding glenoid retroversion and its influence on rotator cuff tears. Nevertheless, as proved by the AUC of the different ROC curves, the coracoid indices (CLD, CLT, CLR, and CA) are superior to humeral version in predicting SS lesions.

Table III Leite-Torres classification of coracoid morphology

Type	Morphology	Angle	Risk of SS tear
I	Flat coracoid	CA > 120°	Coracoid with lowest risk of SS tear development
II	Curved coracoid	CA between 95° and 120°	Coracoid with intermediate risk of SS tear development
III	Hooked coracoid	CA < 95°	Coracoid with highest risk of development of SS tear

SS, subscapularis; *CA*, coracoid angle.

Another strong point in our study is the use of MRI to evaluate humeral version instead of the more common CT scan. MRI’s superiority in evaluating the humeral head cartilage allows a more accurate definition of the humeral head central axis and, therefore, of humeral version. This scenario is complemented by its ability to simultaneously assess rotator cuff integrity and characteristics, defining it as our preferred method when evaluating humeral and coracoid morphology.

However, there are some limitations to our study. Although our MRI protocol stated that the arm should be in a predefined position, variation in patient positioning is always a possibility and may influence the measurements. In addition, despite the implementation of a standardized protocol and implementation of 3 separate and consecutive measures, all measurements were performed by the same observer. Finally, our study was designed as a retrospective study, with its inherent limitations.

Conclusion

This article is, to our knowledge, the first to study the influence of different parameters of the coracoid process morphology on SS tears. It is also the first study to evaluate the role of humeral version in SS injury pathology, proving that this parameter is also a risk factor in anterior rotator cuff injuries. The largest published sample, including 330 patients, also contributes to the strength of this study. Finally, our study was the first to create a classification system according to the coracoid morphology and its relative risk of associated SS tears.

Disclaimer

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