Utility of shoulder radiographic indices in rotator cuff tears diagnosed by ultrasound

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SUMMARY

Rotator cuff (RC) injuries are a common cause of shoulder pain and dysfunction. Their multifactorial etiology includes anatomical and clinical factors. This study evaluates the utility of various radiographic indices in detecting RC tears and explores their correlation with the condition of the long head of the biceps tendon (LHBT). A cross-sectional study was conducted with 150 patients assessed using shoulder radiography and ultrasound. Variables analyzed included acromial slope (AS), acromial tilt (AT), acromial index (AI), subacromial distance (SD), lateral acromion angle (LAA), and critical shoulder angle (CSA). Associations were examined through logistic regression, and predictive models with and without the variable "Age" were compared.

Most injuries affected the supraspinatus tendon and were full tears (72.1%). CSA (OR = 0.798, $p < 0.001$) and SD (OR = 0.559, $p < 0.001$) were the main predictors of RC tears, along with Age (OR = 1.065, $p = 0.003$). The model including Age demonstrated better discrimination ($R^2 = 0.601$). LAA showed a protective trend ($p = 0.053$), while AT, AS, and GP showed no significant associations. This investigation highlights the critical role of specific radiographic measures, particularly CSA and SD, in diagnosing RC tears with age as a significant enhancer of tear likelihood. The findings challenge the conventional utility of several acromial indices and reinforce the interconnectedness of RC pathology with alterations in the LHBT. These insights pave the way for refined diagnostic strategies in clinical settings.

Key words: Rotator cuff – Acromion – Age – Subacromial space – Critical shoulder angle

INTRODUCTION

Rotator cuff (RC) injuries are a common cause of shoulder pain and dysfunction, and they have a considerable impact on the quality of life of the patients (Gomide et al., 2017; Zaid et al., 2019). Although their underlying causes are not completely described, they are thought to have a multifactorial origin that involves both intrinsic and extrinsic factors (Cherchi et al., 2016; Watanabe et al., 2018; Koca et al., 2022; Boulanger et al., 2023; Fallahpour et al., 2023; Schiefer et al.,

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2023; Tunaliwie et al., 2022). The intrinsic factors include age, tendon degeneration, a decrease in vascular supply and genetic predisposition. On the other hand, extrinsic factors, such as repetitive overload and subacromial impingement, have been associated with some acromial anatomical variables and with alterations in the scapulothoracic kinematics (Fallahpour et al., 2023; Schiefer et al., 2023; Melean Quiroga et al., 2015; Ma et al., 2021; Balke et al., 2016; Chalmers et al., 2017; Prietzel et al., 2024; Zeng et al., 2020).

Ever since Neer introduced the concept of "impingement lesions" in 1972, the morphology of the acromion has been subject to special interest as a potential factor in the development of RC tears. Neer put forward the idea that some acromial variations may compress the RC and, consequently, could contribute to the structural damage of the tendon (Neer, 1972). Numerous studies have explored this hypothesis since, by assessing different radiographical parameters of the acromial anatomy to identify which patients have a greater risk of presenting these lesions (Zaid et al., 2019; Morelli et al., 2019). However, the exact role of the acromion in the pathogenesis of RC injuries is still a matter of debate.

In this context, the main goal of this study was to assess the capacity of different radiographic indices used in the analysis of the morphology of the acromion to discriminate between the presence and the absence of RC injuries. Additionally, it aims to identify the RC tendons that are most commonly affected, and to describe their characteristics, as well as to examine possible alterations of the long head of the biceps tendon (LHBT) in the context of RC tears.

MATERIAL AND METHODS

A cross-sectional observational study of diagnostic accuracy in common clinical practice was carried out between March and November 2023.

Study population

The study included patients who were admitted with pain or loss of function in their shoulder, and who had simple radiographs with anteroposterior (AP) and outlet projections, as well as an ultrasound study of the shoulder conducted with the ESAOTE MyLab X9 system and a linear probe (L 4-15). The patients were assessed by the Unit of Musculoskeletal Radiodiagnosis of the University Hospital of Salamanca. Out of the 192 patients who were initially assessed, 42 were ruled out due to the low quality of their radiographs (n=32), a history of shoulder surgery (n=7) or infections/tumors (n=3), and 150 patients were finally selected for the analysis.

Analyzed variables

The following anatomical variables were analyzed in their AP and outlet projections: Acromial slope (AS), Acromial tilt (AT), Acromial index (AI), Lateral acromion angle (LAA), Critical shoulder angle (CSA) and Subacromial distance (SD). The study also registered secondary variables including age, sex and the side of the lesion. The acromial morphology was classified following the categories established by Bigliani et al. (1986) into type I (flat), type II (curved) and type III (hooked) (Fig. 1).

1. Acromial slope

As indicated by Bigliani et al. (1986), AS was measured in outlet radiographs by tracing a line from the most anterior and most inferior point of the acromion to the middle point of its inferior edge. A second auxiliary line goes from the most inferior and most posterior point to the middle point of the inferior edge of the acromion. The acromial slope is the medial or lateral angle formed between these two lines (Fig. 2A). Normal values for AS range between 12º and 15º, and a SA over 15º indicates a higher risk of RC tear due to an increase in acromial compression (Melean Quiroga et al., 2015).

2. Acromial tilt

As established by Kitay et al. (1995) and Aoki et al. (1986), AT was measured in outlet radiographs as the angle formed between the line that goes from the most anterior point of the inferior edge of the acromion to the most posterior point of that edge; and the line that connects the most posterior point of the acromial inferior edge to the end of the coracoid process (Fig. 2B). The literature mentions values of AT between 70º and 90º as a

normal range for shoulders without RC injuries (Melean Quiroga et al., 2015).

3. *Acromial index*

The AI, in line with Nyffeler et al. (2006), was calculated in the AP view as the ratio between the distance from the glenoid fossa to the lateral edge of the acromion (GA) and the distance from the glenoid fossa to the most lateral edge of the humeral head (GH) (Fig. 3A). Previous studies have reported a range of normal values between 0.60 and 0.73 (Melean Quiroga et al., 2015; Balke et al., 2013).

4. *Lateral acromion angle*

As described by Banas et al. (1995), the LAA was measured on the AP projection with a line parallel to the inferior edge of the acromion and a line from the most superior edge to the most inferior edge of the glenoid fossa. The angle between those two lines is the LAA (Fig. 3B). Some authors have suggested a cutoff of 70º to 75º as the lower limit

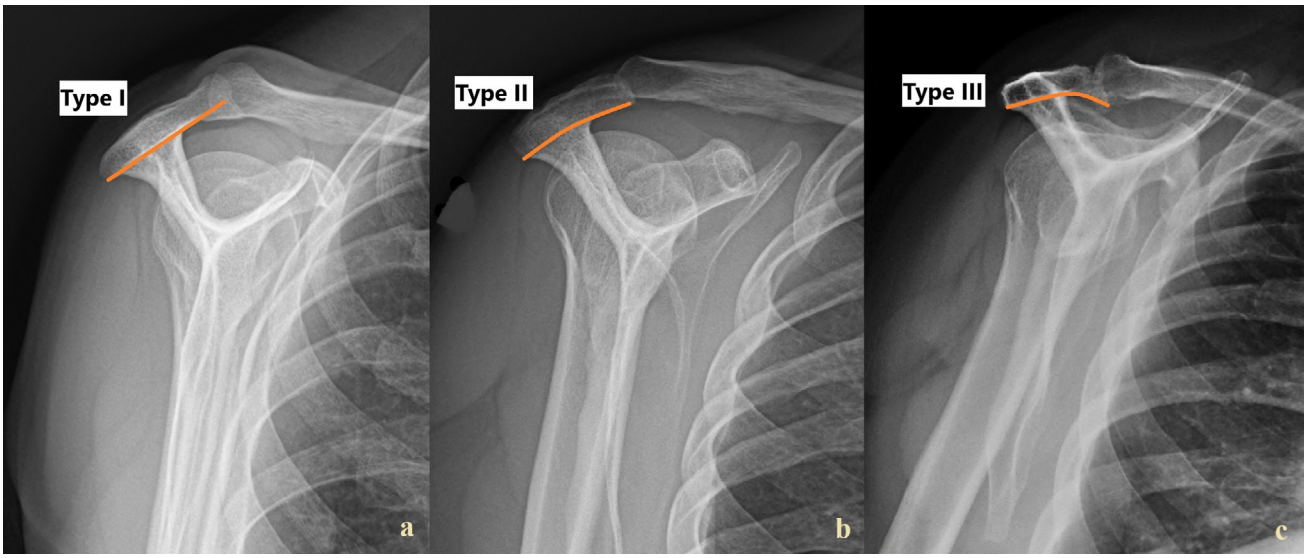

Fig. 1.- Types of acromion based on their morphology as described by Bigliani. a) Type I or "flat". b) Type II or "curved". c) Type III or "hooked".

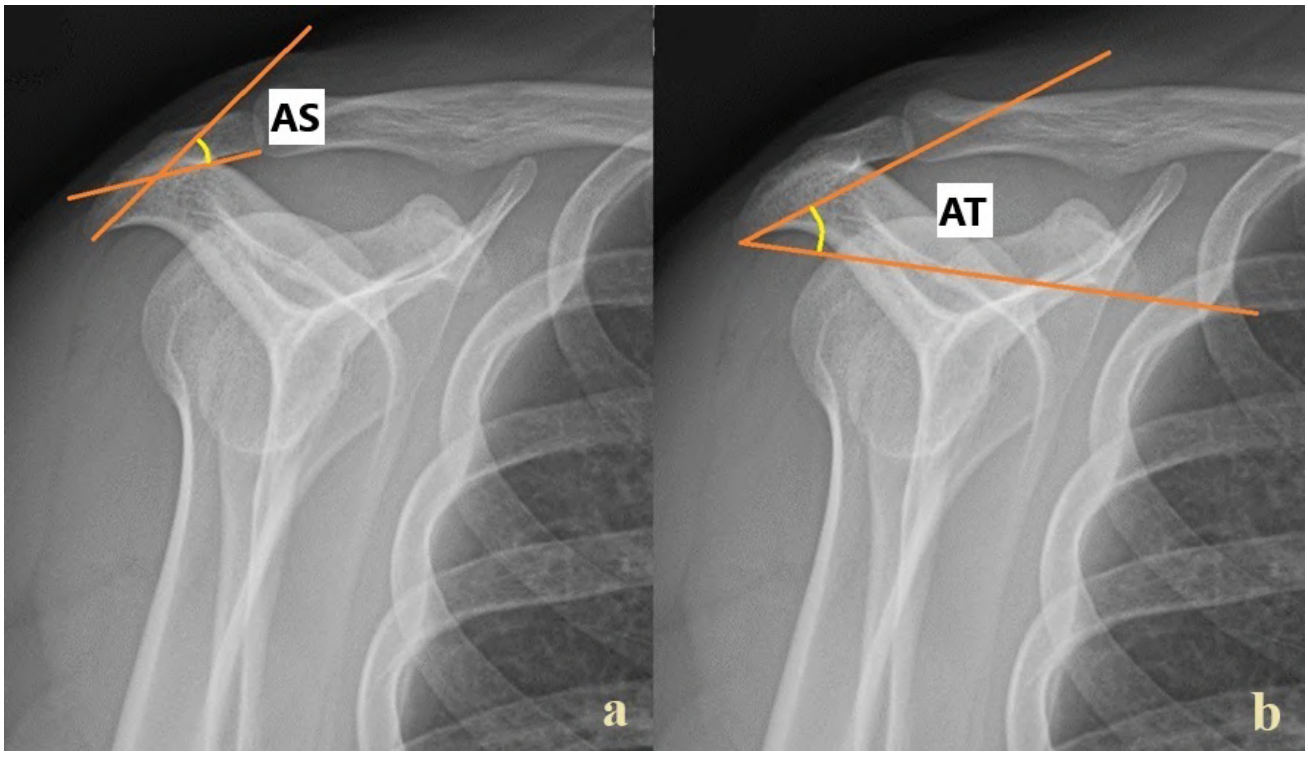

Fig. 2.- Radiographs of outlet projections of the right shoulder showing the acromial slope (AS) and the acromial tilt (AT).

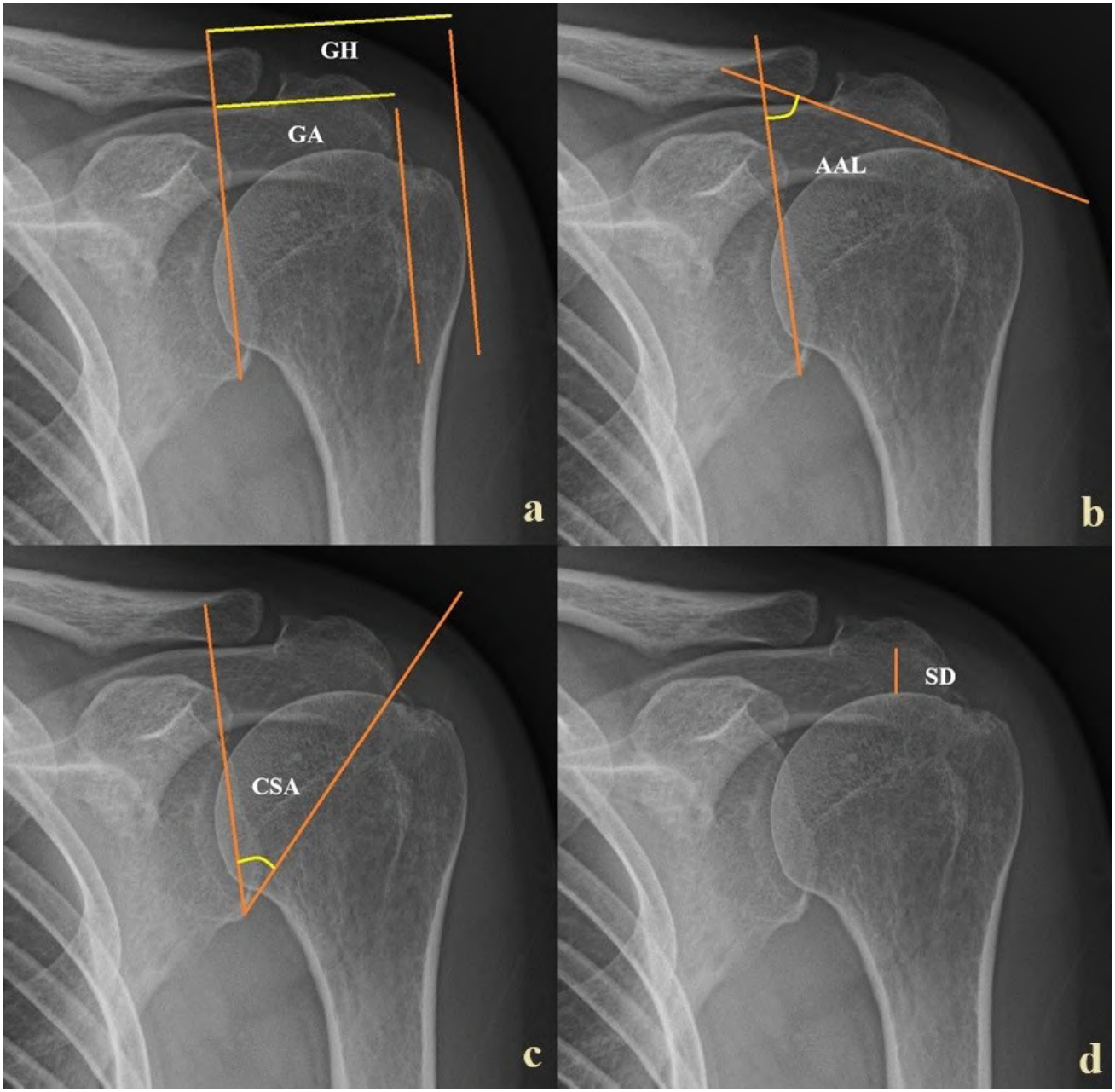

Fig. 3.- Radiographs of AP projections of the left shoulder showing the acromial index (AI) (a), lateral acromion angle (LAA) (b), critical shoulder angle (CSA) (c) and subacromial distance (SD) (d).

of normal (Balke et al., 2013; Banas et al., 1995; Hanciau et al., 2012).

5. Critical shoulder angle

The CSA was measured in AP projections, as indicated by Moor et al. (Moor et al., 2014), by drawing a line from the inferior to the superior edge of the glenoid fossa and another line from the inferior edge of the glenoid fossa to the most inferior and most lateral point of the acromion. The angle between these two lines is the CSA (Fig. 3C). The range of CSA in shoulders without injuries is generally 30º-35º. Values above 35º have been associated with a greater risk of tear, whereas values below 30º could be associated to glenohumeral arthritis (Cherchi et al., 2016; Watanabe et al., 2018; Balke et al., 2013; Banas et al., 1995).

6. Subacromial distance

As indicated by Neer (1972), SD was measured in an AP projection as the distance between the most superior point of the humeral head and the acromial end (Fig. 3D). A normal SD is approximately 10 mm, and values below 7 mm are considered pathological (Neer, 1972).

Assessment of the radiographs

All the radiographs were available digitally and assessed by a radiologist, who was blind to the ultrasound diagnosis, and who verified their quality and conducted the measurements. The measurements of angles and lengths are expressed in millimeters with one decimal place, with the exception of SD, which was initially rounded up but is presented with one decimal place in the results for greater accuracy.

All radiographic measurements were performed twice by the same radiologist in a single session to minimize intraobserver variability. Interobserver agreement was not assessed in this study.

Ultrasound assessment and tendon injuries

The dependent variable was the presence or absence of RC lesions, assessed with standardized ultrasound images of the shoulder conducted by a musculoskeletal radiologist with more than 20 years of experience. The severity of the tears was assessed descriptively, with a difference between partial and full tears, without detailed measurements of the extent of the tear. A tear was classified as full when it affected the entire thickness of the tendon from the surface of the joint to the subacromial/subdeltoid bursa, whereas a partial tear is a focal defect of the tendon that is visible from two orthogonal planes (Fig. 4 and Fig. 5, respectively). The number of tendons involved and alterations in the LHBT were also assessed, including changes in the bicipital groove, and presence of significant fluid collection in the tendon sheath (defined as a volume over physiological levels or pathological fluid which is visible in the ultrasound) (Fig. 6), tears and dislocation.

Statistical analysis

The assessment of associations between the demographic variables and the anatomical parameters of the shoulder with the presence of RC tear used the Mann-Whitney U test for continuous variables and Pearson's chi-squared test for categorical variables.

In order to identify the predictive variables for RC, a multivariate binary logistic regression model was used in order to assess the odds ratio (OR) with 95% confidence intervals. The discriminating capacity was assessed via the sensitivity, specificity, and area under the ROC curve (AUC). ROC curves were generated to compare the discriminating capacity of the models that included or excluded not include the variable "Age" both graphically and numerically. In addition, Nagelkerke's R^2 was used as a global adjustment, and Youden's index was used to establish the optimal cutoff in each case.

All the analyses were conducted with Python (v 3.8), with a significance level of $p < 0.05$.

Ethical approval

The study was approved by the Ethics Committee of the Salamanca Health District, Spain (CEIm reference code: PI 2024 04 1592-TD).

RESULTS

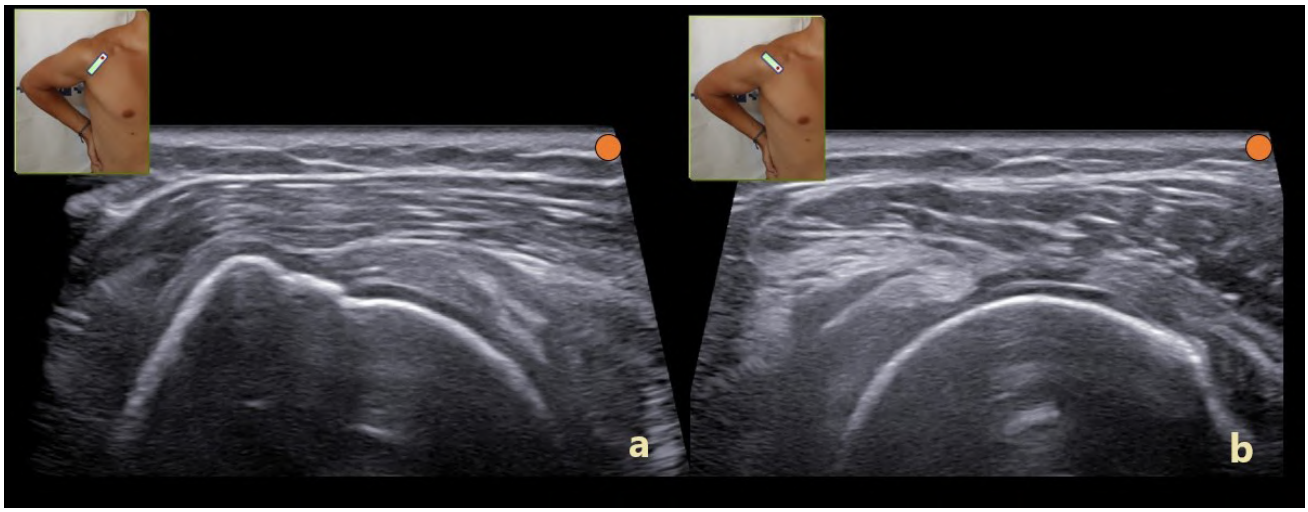

Fig. 4.- Full tear of the insertional fibers in the middle third of the supraspinatus tendon seen in longitudinal (a) And transverse planes (b).

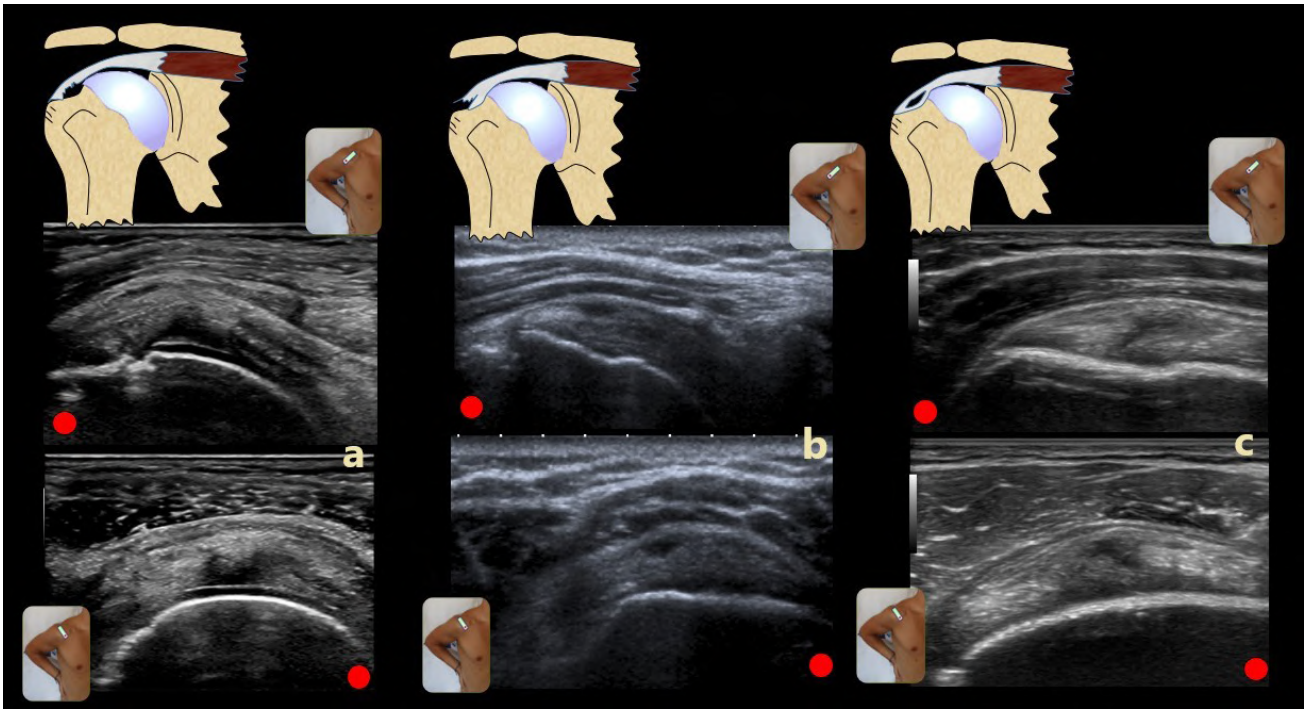

Fig. 5.- Ultrasound examples of partial tears of the supraspinatus tendon with different patterns: articular (a), bursal (b) and intrasubstance (c).

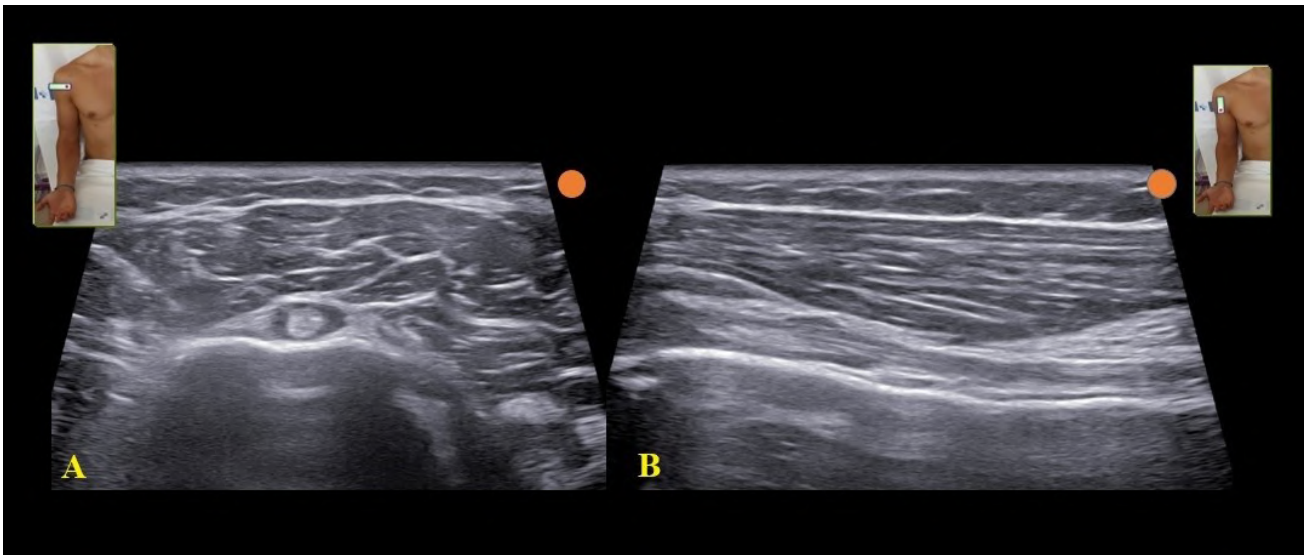

Fig. 6.- Ultrasound images of transversal (A) and longitudinal sections (B) of the long head of biceps tendon that shows thickening and increased fluid collection in the synovial sheath that completely surrounds the tendon.

A total of 150 patients were analyzed. 68 (45.3%) presented RC tear, and 82 (54.7%) had an intact RC. The average age was significantly higher in the group with RC tear (65.7 years) than in the group with an intact RC (55.4 years; $p < 0.001$). No statistically significant differences were observed regarding sex ($p = 0.309$). The distribution of the injured shoulder (left or right) and the morphology of the acromion were not significantly associated with the presence of a tear.

Within the group of patients with RC tear, the supraspinatus tendon was the one most commonly affected, with lesions in 70.6% of the cases. The subscapularis tendon was affected by itself in only one case, and no independent lesions of the infraspinatus tendon or the teres minor tendon were registered. The involvement of multiple tendons was less common, and it mainly consisted of the combination of the supraspinatus and the subscapularis tendons (13.2%). Most of the patients presented lesions in only one tendon (73.5%), followed by lesions in two (16.2%) or three tendons

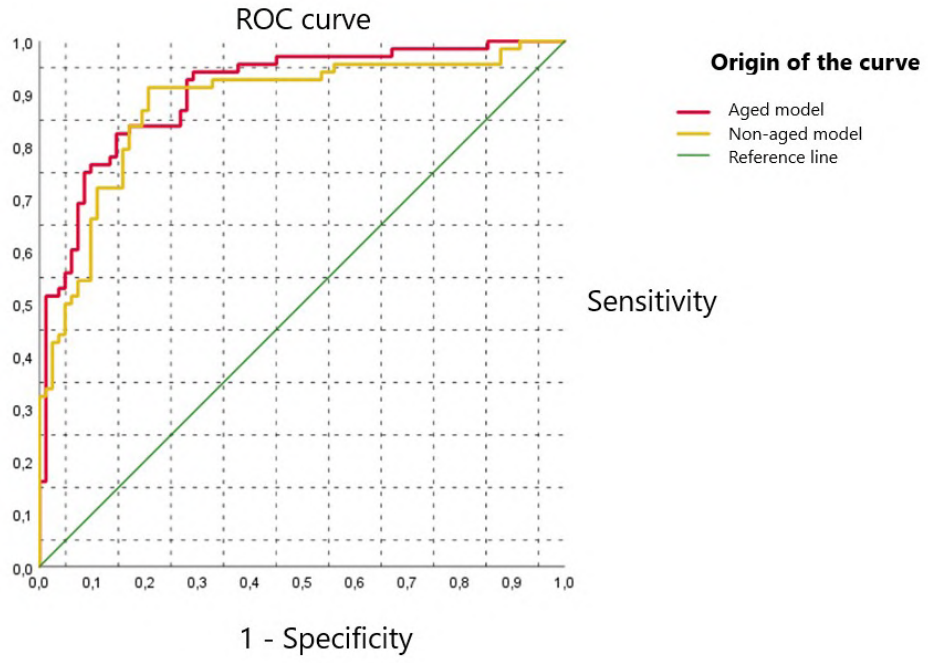

Fig. 7.- Comparative ROC curves of the predictive analysis of the models that included the variable Age (red line) and excluded it (yellow line).

(10.3%). Regarding the type of tear, there were more full tears (72.1%) than partial tears (27.9%).

With regard to alterations in the LHBT, tendinopathic changes were observed at the start of the bicipital groove in 11.8% of the patients with tears and 41.5% of the control group. Other alterations, such as the presence of tendinopathy and a significant fluid collection in the tendon sheath, were more common in the group with RC tears (69.1% vs 54.9%). The combination of tendinopathy and LHBT tear was more common in the group with RC tear (11.8% vs. 3.7%), whereas the combination of tendinopathy and dislocation was only observed in the group with RC tear (7.4%).

Patients with RC tear presented higher mean values of AS (20.3° vs. 16.4°; $p < 0.001$), AT (37.1° vs. 34.1°; $p = 0.002$), AI (0.79 vs. 0.72; $p < 0.001$) and CSA (40.9° vs. 37.4°; $p < 0.001$), while the group without RC tear presented significantly higher values of LAA (77.0° vs. 70.9°; $p < 0.001$) and SD (10.2 mm vs. 8.46 mm; $p < 0.001$). These results are summarized in Table 1.

Table 2 shows the results of the multivariate binary logistic regression analysis. Three factors were significantly associated with RC tear: CSA (OR = 0.798; 95% CI: 0.712– 0.895; $p < 0.001$), SD (OR = 0.559; 95% CI: 0.408–0.766; $p < 0.001$) and Age (OR = 1.065; 95% CI: 1.022–1.110; $p = 0.003$). These results show that a higher CSA and a lower SD are associated with a greater risk of tear, whereas Age significantly increases this risk. For its part, LAA was nearly significant (OR = 0.856; 95% CI: 0.731–1.002; $p = 0.053$), which suggests a potential association with a lower risk of tear. Other indices, such as AS, AT and AI, were not significantly associated with the presence of tears.

Two logistic regression models were developed for closer analysis of the variable Age: one which included this variable and one which excluded it (Table 3). The model with Age as a variable showed better statistical adjustment (adjusted $R^2 = 0.601$) and greater balance between sensitivity (82.4%) and specificity (85.4%), and Youden's index was 0.484 as cutoff. This model also showed elevated and balanced positive and negative predictive values (PPV: 82.4%; NPV: 85.4%). For its part, the model without Age as a variable had a lower adjusted R^2 value (0.549). Although it showed better sensitivity (91.2%) and a slightly higher NPV (91.5%), it reduced its specificity (79.3%) and PPV (78.5%), with Youden's index as cutoff at 0.348.

In order to compare the discriminating capacity of both models, the ROC curves were generated (Fig. 7). The model that included Age (red line) showed a better performance for most specific-

Table 1. Statistical data and details of lesions found in the patients.

	Tear	No tear	
	(n=68)	(n=82)	p
Age, years (mean ± α)	65.7 ± 11.8	55.4 ± 12.8	<0.001
Sex, n (%)			0.237
Women	43 (63.2%)	44 (53.7%)	
Men	25 (36.8%)	38 (46.3%)	
Injured shoulder, n (%)			0.979
Right	38 (55.9%)	46 (56.1%)	
Left	30 (44.1%)	36 (43.9%)	
Morphology of the acromion, n (%)			0.62
Type I	7 (10.3%)	5 (6.1%)	
Type II	59 (86.8%)	75 (91.5%)	
Type III	2 (2.9%)	2 (2.4%)	
Injured tendon, n (%)			<0.001
Supraspinatus	48 (70.6%)	0.0 (0.0%)	
Infraspinatus	0 (0.0%)	0.0 (0.0%)	
Subscapularis	1 (1.5%)	0.0 (0.0%)	
Teres minor	0 (0.0%)	0.0 (0.0%)	
Supraspinatus + Infraspinatus	2 (2.9%)	0.0 (0.0%)	
Supraspinatus + Subscapularis	9 (13.2%)	0.0 (0.0%)	
Supraspinatus + Infraspinatus + Subscapularis	7 (10.3%)	0.0 (0.0%)	
None	0 (0.0%)	82 (100%)	
Number of injured tendons, n (%)			<0.001
0	1 (1.5%)	82 (100%)	
1	49 (72.1 %)	0.0 (0.0%)	
2	11 (16.2%)	0.0 (0.0%)	
3	7 (10.3%)	0.0 (0.0%)	
Type of tear, n (%)			<0.001
Full	49 (72.1%)	0 (0.0%)	
Partial	19 (27.9%)	0 (0.0%)	
None	0 (0.0%)	82 (100%)	
Long head of the biceps tendon (LHBT) with tendinopathy, n (%)			<0.001
Changes in bicipital groove	8 (11.8%)	34 (41.5%)	
Changes in bicipital groove + fluid collection	47 (69.1%)	45 (54.9%)	
Changes in bicipital groove + tear	8 (11.8%)	3 (3.7%)	
Changes in bicipital groove + dislocation	5 (7.4%)	0 (0.0%)	
Acromial slope, º (mean ± a)	20.3 ± 6.43	16.4 ± 4.74	<0.001
Acromial tilt, º (mean ± a)	37.1 ± 6.21	34.1 ± 5.59	0.002
Acromial index (mean ± a)	0.79 ± 0.08	0.72 ± 0.06	<0.001
Lateral acromion angle, º (mean ± a)	70.9 ± 5.67	77.0 ± 5.23	<0.001
Critical shoulder angle, º (mean ± a)	40.9 ± 4.72	37.4 ± 4.52	<0.001
Subacromial distance, mm (mean ± a)	8.46 ± 1.85	10.2 ± 1.51	<0.001

Table 2. Results from the multivariate binary logistic regression analysis of the variables associated with RC tear.

	B	Standard error	Sig.	OR	CI<95%	CI>95%
Acromial slope, º	0.056	0.043	0.189	1.058	0.973	1.151
Acromial tilt, º	0.003	0.044	0.941	1.003	0.921	1.093
Acromial index	7.759	4.834	0.109	2341.8	0.180	30520479
Lateral acromion angle, º	-0.156	0.081	0.053	0.856	0.731	1.002
Critical shoulder angle, º	-0.225	0.058	<0.001	0.798	0.712	0.895
Subacromial distance, mm	-0.582	0.161	<0.001	0.559	0.408	0.766
Age	0.063	0.021	0.003	1.065	1.022	1.110

Table 3. Comparison of predictive metrics between logistic regression models with and without the variable "Age".

	With Age	Without Age
Quality of adjustment (adjusted R2)	0.601	0.549
Sensitivity (%)	82.4	79.4
Specificity (%)	85.4	84.1
Positive predictive value (VPP, %)	82.4	80.6
Negative predictive value (VPN, %)	85.4	83.1
Optimal cutoff (Youden's Index)	0.484	0.348
Sensitivity for optimal cutoff (%)	82.4	91.2
Specificity for optimal cutoff (%)	85.4	79.3
PPV for optimal cutoff (%)	82.4	78.5
NPV for optimal cutoff (%)	85.4	91.5

ity values, which represents greater predictive capacity and general sensitivity. In contrast, the model that did not include Age (yellow line) also showed good discriminating capacity, albeit lower, in line with the lower statistical adjustment that was described.

DISCUSSION

This study analyzes different demographic, anatomical and clinical factors associated with RC lesions, and provides a comprehensive overview of their diagnostic relevance. Although some previous studies have suggested that sex may have an influence on the prevalence of these lesions, our analysis did not find significant differences in this regard, in contrast with previous research that reported a greater prevalence of RC tears in men (Prietzel et al., 2024). Similarly, no relevant association was found between the shoulder that was affected (right or left) and the presence of lesions, in line with previous studies which also did not find a significant correlation (Tashjian et al., 2010; Reilly et al., 2006).

With regard to the acromial morphology, type II or curved was the most common in our sample, in line with the data found in the literature. However, there was a higher prevalence of the acromion type I (flat) than type III (hooked), which contrasts with the findings presented by Chaimongkhol et al. (Chaimongkhol et al., 2020). Even though there are many studies and meta-analyses that have observed an association between acromion type III and RC disorders (Gomide et al., 2017; Cherchi et al., 2016; Fallahpour et al., 2023; Prietzel et al., 2024; Zeng et al., 2020; Bigliani et al., 1986; Singleton et al., 2017; Carbonel Bueno et al., 2023; Edelson et al., 1992), our results did not reveal a significant relationship. This could be explained by the inherent limitations in Bigliani's classification, whose low inter-observer reliability has been widely reported (Cherchi et al., 2016; Prietzel et al., 2024; Singleton et al., 2017).

Regarding the characteristics of the lesions, full tears were found more often (72.1%) than partial tears (27.9%), unlike in other studies conducted with magnetic resonance imaging (MRI), such as

the one by Fallapour et al. (2023). Alterations in the LHBT were more common in patients with RC alterations, including tendinopathic changes and fluid collection in the tendon sheath (69.1%), tear (11.8%) and dislocation (7.4%). These results are in line with those from studies such as the one by Ahrens and Boileau (2007) or Kijima et al. (2017), which suggests that these alterations might be associated with repeated friction and traction in the glenohumeral joint, generated by the ascending migration of the humeral head in shoulders with dysfunctional RC.

Our multivariate analysis identified three variables that were significantly associated with RC tears: CSA, SD and Age. These findings match those from previous studies that have pointed out the relevance of these variables in the pathogenesis of RC injuries (Cherchi et al., 2016; Watanabe et al., 2018; Melean Quiroga et al., 2015; Balke et al., 2013). CSA showed a direct association with RC tears (OR = 0.798; $p < 0.001$), which reinforces the hypothesis that a greater CSA increases the probability of subacromial compression and, consequently, the risk of tendon tears. This finding is in line with those from studies such as the one by Moor et al. (2014), which suggest that angles greater than 35° are strong predictors for tears, whereas lower values can be associated with other pathologies, such as glenohumeral arthritis (Zaid et al., 2019; Cherchi et al., 2016; Zeng et al., 2020; Tang et al., 2019; Incesoy et al., 2021). In this same line, a lower SD was also significantly associated with RC tears (OR = 0.559; $p < 0.001$), with lower average values in the affected group (8.46 ± 1.85 mm, $p < 0.001$). These findings match those from studies that found an association between a reduced SD and subacromial impingement syndrome and RC tears (Koca et al., 2022; Boulanger et al., 2023; Björnsson et al., 2021). These parameters show a greater risk of supraspinatus tendon impingement, which has been extensively documented in the literature since the first studies by Neer (1972).

Age was a significant factor, with OR: 1.065, which represents an increased risk of tears by 6.5% for each additional year of life. This finding is consistent with the literature, which describes age-associated tendon degeneration as a key factor in the development of RC lesions (Gomide et al., 2017; Cherchi et al., 2016). Also, when comparing the models with and without the variable Age, we observed that the inclusion of this parameter significantly improves the discriminating capacity of the model, as shown by the higher value for adjusted R^2 and a better balance between sensitivity and specificity.

On the other hand, LAA was almost statistically significant (OR = 0.856; $p = 0.053$), which suggests a potential protective effect against RC tears. However, additional studies are required with greater statistical power to confirm this potential relationship and define a clinically relevant threshold (Zaid et al., 2019; Banas et al.., 1995).

In contrast, AT, AI and AS did not show a significant association with RC tears, unlike in previous studies (Kitay et al., 1995; Aoki et al; 1986; Nyeffeler et al., 2006; Balke et al., 2013). Even though some authors have associated these parameters with a greater risk of tears, our results did not manage to replicate this relationship. For example, while studies such as the one by Nyffeler et al. (2006) suggest that greater AI is associated with lesions, other studies, including ours, did not observe this association (Tang et al., 2019). Similarly, AS has shown different results in the literature: some studies have reported greater values in patients with non-traumatic tears (Balke et al., 2016), but our sample did not reveal any significant association.

Limitations and Strengths

Our study has some limitations, such as the lack of information on the dominant side of the shoulder and the history of traumatic events, and these factors could have an influence on the risk of RC tears (Kijima et al., 2017). Also, the diagnosis of the lesions was obtained exclusively with ultrasounds, without confirmation with other more sensitive methods such as MRI or arthroscopy, which could affect the accuracy and reproducibility of the findings. The predominant presence of elderly and Caucasian patients limits the extrapolation of results to other populations.

One strength is the use of simple radiographs as a diagnostic tool, which increases its applicability

in clinical and healthcare environments.

CONCLUSIONS

This study highlights the importance of some anatomical parameters, mainly CSA and SD, in the assessment of RC lesions. It has been observed that a high CSA and a reduced SD are significantly associated with the presence of tears. However, other anatomical indices such as AT, AI and AS did not show a significant association, which suggests that they are not universal factors in the prediction of RC tears, and that their clinical applicability may depend on the study population. Also, age was a significant independent factor that increases the risk of tear, and this finding underscores its key role in the evolution of this pathology.

With regard to the characteristics of the lesions, full RC tears were more common than partial tears. Also, the elevated prevalence of LHBT alterations observed in patients with RC tears reinforces the relationship between RC disorders and its effects on other associated structures, which reveals the integral nature of the musculoskeletal system of the shoulder.

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