Magnetic resonance imaging based coracoid morphology and its associations with subscapularis tears: a new index

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Abstract

Background: We aimed to assess the validity of magnetic resonance imaging (MRI) in assessing the subcoracoid space and determine the validity of novel sagittal plane subcoracoid space measurements.

Methods: We assessed 33 arthroscopically proven subscapularis tears with MRIs compared to 33 (instability) controls with normal subscapularis tendons. Three examiners analyzed MRIs for seven static indices of coracoid morphology, in axial and sagittal planes. We explored reviewer variation using intraclass correlation coefficients (ICC) and differences between the two groups was explored using t-tests.

Results: Groups were similar in characteristics but different in age (cases = 53, controls = 23). ICC showed good (2/7) or excellent (5/7) reliability. Small differences (<1.6 mm) were identified between subscapularis tears and controls in coraco–humeral distance, in axial ($p = 0.092$) and sagittal planes ($p = 0.045$). There were statistically significant differences between groups when analyzing the angular projection of the coracoid from the glenoid, in both sagittal ($p < 0.0001$) and axial planes ($p = 0.045$).

Conclusions: Acute inferior angulation of the coracoid in the sagittal plane may be associated with subscapularis tears. Static indices are measured within the scapula and not affected by arm position. MRI reliably provided a platform to assess the coracoid. Based on this, we currently consider coracoplasty in patients with subscapularis tears and a sagittal coraco–glenoid angle $<60^\circ$ to reduce potential impingement.

Keywords

coracoid anatomy, MRI, rotator cuff, subscapularis, subcoracoid impingement

Date received: 1st December 2016; revised: 15th October 2017; accepted: 24th October 2017

Introduction

Rotator cuff tears form a common cause of disability in the community, with an increasing incidence as the population ages.¹ There is increasing evidence that surgical repair of rotator cuff tears results in improvement in symptoms and functional outcome, particularly in working age patients.² There is also evidence that the procedure is beneficial to the community in terms of lost productivity.³

Tears of the subscapularis tendon have been reported as making up between 31% and 37% of all rotator cuff tendons repaired.^{4,5}

There has been conflicting evidence on the role of local anatomy in the aetiology of tears of the

subscapularis tendon. Gerber et al.⁶ first described the anatomy of the subcoracoid space in 1985,⁶ stating that the subcoracoid space decreases with forward flexion, adduction and internal rotation. Furthermore, Gerber et al.⁷ described subcoracoid impingement syndrome, documenting conflict between the coracoid and anterior humeral head, including the subscapularis tendon, and also described measuring the distance the

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coracoid projects laterally from the plane of the glenoid: the coracoid overlap. The coraco–glenoid angle was defined as an angle subtended by a line along the plane of the glenoid face and a line projecting from the anterior edge of the glenoid to the lateral edge of the coracoid in the axial plane.⁷ There was a positive correlation between a small coraco–glenoid angle and subcoracoid impingement, particularly when combined with a small coracoid overlap.⁷ It has been suggested that a coraco–humeral distance of less than 6 mm in the axial plane is also associated with subscapularis tendon tears.⁸

Richards et al.⁹ confirmed this distance of 6 mm in a case series, comparing the bony coraco–humeral distance on pre-operative magnetic resonance imaging (MRI) of 36 cases of subscapularis tears and 36 controls. It was found that the average coraco–humeral distance was 5 mm in the case group versus 10 mm in the control group. This was only analyzed in the axial plane.

However, Nove-Josserand et al.¹⁰ group analyzed computed tomography (CT) arthrograms of 206 patients with proven rotator cuff tears, and found that there was no association between coraco–humeral distance and tears of the rotator cuff tendons. They also analyzed a subgroup of isolated subscapularis tears in 57 cases, and found no relationship between size of the anterior subcoracoid space and subscapularis tears. In a separate group that had massive tears, including a subscapularis tear, there was a diminished coraco–humeral distance, which was postulated to be the result of anterior–posterior force couple imbalance. In this situation, unopposed infraspinatus anteriorly translates the humeral head, decreasing the coraco–humeral distance.

Most of the studies investigating coraco–humeral distance have involved measuring the relative position of the coracoid and the humeral head. This interval changes with position of the arm, which is not always controlled for when taking images.¹¹ We aimed to investigate whether markers of coracoid morphology that are solely within the scapula may be associated with subscapularis tears. We assessed the previously described measures of the relative position between the humeral head and the coracoid. Also, given that most previous investigations have focused on the axial plane, we considered the coracoid morphology in the axial and sagittal planes.

Our null hypothesis was that the relationship of the coracoid and the humeral head in the axial and sagittal planes is not associated with subscapularis tears (compared to a control group with shoulder instability).

Materials and Methods

A negligible risk ethics proposal was accepted by our institutional review board (HREC 15/118). To ensure a

comprehensive list, two regional surgical databases (Public and Private) were searched for arthroscopic rotator cuff tendon repair performed from January 2010 to January 2016. Concomitant supraspinatus or infraspinatus repairs were accepted, although massive and or irreparable tears were excluded.

Inclusion criteria

- Subscapularis tendon tear proven at arthroscopic repair
- Age 18 years to 70 years
- Pre-operative MRI

Exclusion criteria

- Significant degenerative disease
- Massive irreparable cuff tear, requiring tuberoplasty or debridement only
- Subscapularis tear noted, but not repaired. Delamination with less than one-third of tendon torn and minimal exposed footprint
- Previous surgery on the affected shoulder

A control group was identified with a matched number of patients from a consecutive series of shoulder instability cases with pre-operative MRI who were treated arthroscopically. The control group was matched for sex. Any instability cases with associated rotator cuff tears were excluded from the control group. This group was chosen because they had radiologically and arthroscopically proven intact subscapularis tendon.

All included patients were de-identified and their MRI scans were reviewed by three independent examiners: two fellowship trained orthopaedic shoulder surgeons and an orthopaedic advanced trainee. Standard, calibrated measurement tools from within the digital image viewer were used. Each assessor was given an introduction to the methods of measuring seven indices of coracoid morphology (Fig. 1). These were independently measured by each assessor once.

Coraco–humeral distance is defined as the narrowest point between the coracoid and the humerus on the axial slices (axial coraco–humeral distance)^{7–9} and sagittal slices (sagittal coraco–humeral distance) (Fig. 1a, e). This is achieved by scrolling through the images until the narrowest space is visualized and the distance is measured between the closest components of each structure. Coraco–subscapular distance is the narrowest point between the coracoid and the subscapularis tendon in the axial plane (axial coraco–subscapular distance) (Fig. 1b) and sagittal plane (sagittal coraco–subscapular

Figure 1. Coracoid morphology indices. (a) Axial coraco–humeral distance. (b) Axial coraco–subscapular distance. (c) Axial coracoid overlap. (d) Axial coraco–glenoid angle. (e) Sagittal coraco–humeral distance. (f) Sagittal coraco–subscapular distance. (g) Sagittal coraco–glenoid angle.

distance) (Fig. 1f). This is taken on the same image as Fig. 1(a, e) but measuring the distance between the coracoid and the subscapularis tendon. Coracoid overlap was measured as described by Gerber et al.⁷ (Fig. 1c). Coroco–glenoid angle was measured in both the axial (axial coraco–glenoid angle) (Fig. 1d) and sagittal planes (sagittal coraco–glenoid angle) (Fig. 1g). The axial coraco–glenoid angle is an angle subtended by a line along the plane of the glenoid face and a line projecting from the anterior edge of the glenoid to the lateral edge of the coracoid in the axial plane.⁷ In some instances, the lateral edge of the conjoint tendon was used as a surrogate for the lateral edge of the coracoid to allow the glenoid face to be more accurately assessed. The sagittal coraco–glenoid angle is measured by scrolling centrally on the sagittal images until the glenoid rim is seen. The first line of this angle is drawn along the anterior rim of the glenoid, whereas the second line starts from the middle of the coracoid base and projects to the tip of the coracoid as seen on the same image (Fig. 1g).

Statistical analysis was undertaken using R, version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria) presenting continuous data as medians with the range or means with the standard deviation or

confidence interval when describing the difference between two means. Categorical data are presented as % and ‘*n*’. Measures of dispersion were calculated in the form of the standard deviation. Intraclass correlation coefficient (ICC) estimates and their 95% confident intervals were calculated using SPSS, version 24 (IBM Corp., Armonk, NY, USA) based on a mean-rating ($k=3$), absolute-agreement, two-way mixed-effects model. This is based on methodology described by Oh et al.¹² The ICC can be interpreted when considering inter-rater agreement as <0.4 as poor agreement, 0.40 to 0.59 as fair agreement, 0.6 to 0.75 as good agreement and 0.75 to 1.0 as excellent.¹³

The data were found to be normally distributed with no significant outliers. The difference between the means of the control and case groups was then analyzed using an unpaired *t*-test, including its 95% confidence intervals. Sample size was determined by the size of the number of cases meeting the inclusion criteria and was accepted because it was in keeping with previous studies.^{8,14} Linear correlation analysis was performed on the association between coracoid overlap and axial coraco–glenoid angle, and then multiple *t*-tests were performed to identify any difference between cases and controls.

Table 1. Results summary.

Measurement	Intraclass correlation coefficient (95% CI)	Case group, mean (SD)	Control group, mean (SD)	Difference in means (95% CI)	p-value
Axial CHD	0.85 (0.77 to 0.9)	8.11 (0.45)	9.05 (0.31)	-0.95 (-2.05 to 0.16)	0.092
Axial CSD	0.78 (0.52 to 0.89)	2.93 (0.34)	2.90 (0.20)	0.03 (-0.76 to 0.82)	0.94
Axial CO	0.93 (0.89 to 0.96)	16.17 (0.89)	17.16 (0.78)	-0.99 (-3.35 to 1.37)	0.405
Axial CGA	0.68 (0.31 to 0.84)	37.02 (1.13)	40.56 (1.31)	3.54 (-7.01 to -0.07)	0.045
Sagittal CHD	0.90 (0.85 to 0.94)	9.84 (0.53)	11.50 (0.62)	-1.66 (-3.23 to -0.04)	0.045
Sagittal CSD	0.86 (0.69 to 0.93)	4.15 (0.46)	4.90 (0.50)	0.76 (-2.12 to -0.61)	0.27
Sagittal CGA	0.72 (0.51 to 0.83)	57.35 (1.82)	69.73 (1.96)	-12.38 (-17.71 to -7.05)	<0.0001

CHD, coraco-humeral distance; CSD, coraco-subscapular distance; CO, corocoid overlap; CGA, coraco-glenoid angle;

Results

The median age of the case group was 55 years (range 27 years to 70 years), whereas that of the control group was 22 years (range 14 years to 41 years), which, as expected, was statistically significant ($p < 0.001$). In total, 75.8% of the case group was male versus 84.8% of the control group ($p = 0.41$). The right limb was affected in 57.5% of cases versus 60.6% of the control group ($p = 0.87$). The subscapularis tears were partial thickness in 66% of tears, with between one-third and two-thirds of the footprint exposed. Ten of 32 (31%) patients had approximately one-third of the footprint exposed and 11 of 32 (34%) had two-thirds of the footprint exposed. The subscapularis tear was functionally complete in 11 of 32 (34%) patients, with more than two-thirds of the footprint exposed but not chronically retracted. We consider chronic retraction as an indication for open repair and augmentation with a split pectoralis major tendon transfer. Twenty-five of 32 (78%) patients had concomitant rotator cuff tears, 15 of 32 (47%) patients had full-thickness supraspinatus tears, seven of 32 (22%) patients had partial thickness supraspinatus and three of 32 (9%) patients had supraspinatus and infraspinatus partial thickness tears.

The ICC is presented in Table 1. We found excellent inter-rater reliability for all measures, except sagittal coraco-glenoid angle (ICC=0.72) and axial coraco-glenoid angle (ICC=0.68), which showed good reliability.

The mean axial coraco-humeral distance in the case group was greater than the previously stated 6mm. There was a difference of less than 1mm between the mean of the control group [mean (SD) 9.05 (0.31) mm] and the subscapularis tear group [mean (SD) 8.11 (0.45) mm] ($p = 0.092$). The overall

size of the subcoracoid space is small, with measurements of the distance between the coracoid and subscapularis, axial coraco-subscapular distance (mean of 2.9mm in both groups) and sagittal coraco-subscapular distance (mean of 9.8mm in the case group and 11.5mm in the control group.). Sagittal coraco-humeral distance was shown to be significantly smaller in the case group [mean (SD) 9.8 (0.53) mm] than the control [mean (SD) 11.5 (0.62) mm] ($p = 0.045$). There was a significant difference in the axial coraco-glenoid angle ($p = 0.045$) and the sagittal coraco-glenoid angle ($p < 0.0001$), with ICC suggesting good agreement. A strongly positive relationship was found between coracoid overlap and axial coraco-glenoid angle. This is because the measurements are taken on the same axial slice of the MRI and measure the lateral projection of the coracoid in the axial plane. A Pearson correlation was performed for the subscapularis tear group, which found an r -value of 0.8081, with $p < 0.0001$. A Pearson correlation was performed for the control group, which found an r -value of 0.8350, with $p < 0.0001$. Multiple t -tests were performed to investigate any correlation between these measures, as well as a Pearson correlation between a ratio of the measures (of corocoid overlap/axial coroco-glenoid angle (CO/ACGA) ($r = -0.02297$, $p = 0.8990$).

Discussion

Rotator cuff tears are a common cause of morbidity and may be influenced by local scapular morphology.¹⁵ Tears of the subscapularis tendon have been linked to the morphology of the coracoid process, although there has been debate regarding the strength of this association. The axial coraco-humeral distance has

traditionally been used to assess this space, with a threshold of <6 mm being linked to higher risk of tears.^{7,9} We found a statistically significant difference between cases with a known subscapularis tear and a control group without a tendon tear. However, our mean was above the 6-mm cut-off and the difference was less than 1 mm. Although our inter-observer agreement was excellent for this measure, we consider that, in practice, a difference of less than 1 mm has limited clinical value.

One previous article has assessed the coraco–humeral space in the sagittal plane, and focused on the vertical distance between the supraglenoid tubercle and the coracoid tip.¹⁶ It found that, the greater the inferior projection of the coracoid from the supraglenoid tubercle, the more likely there was to be a radiological rotator cuff tear. A higher association was found with supraspinatus lesions (53%) than with subscapularis lesions (42%). The included pathology ranged from tendonopathy to complete tears. We assessed the sagittal plane anatomy of the subcoracoid space using three measures (sagittal coraco–humeral distance, sagittal coraco–subscapular distance and sagittal coraco–glenoid angle), focusing on arthroscopically proven rotator cuff tears only. There was a statistically significant difference between groups in the sagittal coraco–humeral distance measurement, with a mean difference of 1.66 mm smaller in those with subscapularis tears ($p=0.045$). This index has not been previously measured and may be a useful means of assessing the subcoracoid space for future studies. The inter-observer agreement for these sagittal indices showed substantial agreement.

The sagittal coraco–glenoid angle was also statically significantly different between groups ($p<0.0001$), with a smaller angle indicating more inferior and less anterior projection of the coracoid from the anterior Glenoid rim. This correlates with the study by Porter et al.¹⁶ suggesting that the inferior projection of the coracoid is associated with cuff pathology. The present study has the benefit of only including subscapularis tendon tears that require surgery, which have been confirmed intra-operatively. This is a new finding and has changed our practice in that we now consider coracoplasty in patients with a sagittal coraco–glenoid angle of less than 60°.

Plain X-ray, CT and MRI have all been used to assess the subcoracoid space.^{15–20} X-ray gives an overview but, because of the complex shape of the coracoid, specific indices of its morphology have poor inter-observer error.¹⁷ Bony anatomy of the coracoid process is visualized well using CT. However, this is not the imaging modality of choice in most centres when assessing rotator cuff tears and thus is rarely ordered pre-operatively unless bony procedures are being

considered.¹⁸ MRI has the advantage of unparalleled soft tissue definition and is commonly used pre-operatively to assess rotator cuff pathology.¹⁹ It would be advantageous if it could also be used to assess the subcoracoid space, requiring no additional imaging. There has been some debate on the validity of MRI to assess bony detail and its relationship to subscapularis tears. Giaroli et al.²⁰ found that they could assess the anatomy well, although MRI assessment of coraco–humeral distance was poorly predictive of subcoracoid impingement clinically. Our high ICC for all measures supports the validity of assessing the subcoracoid space using MRI, as supported by a recent study confirming the validity of using MRI to assess glenoid version. (Unpublished data by Maister N, Hely A, Twycross L, Zhang Y and Page RS)

A limitation of using coraco–humeral distance as a determinate of risk of subcoracoid impingement is that the distance may change with position of the arm.¹¹ The arm is generally kept at the side for MRI, although no standardized control of rotation of the shoulder is enforced. Our control group did not have imaging in abduction/external rotation view. Thus, any interval measured between the scapula and humerus has some inherent unreliability. However, measurements taken solely within the scapula (coracoid overlap, axial coraco–glenoid angle, sagittal coraco–glenoid angle) will not change with arm positioning, making them appealing. We found no difference between groups in coracoid overlap but found statistically significant differences in the axial coraco–glenoid angle ($p=0.045$) and the sagittal coraco–glenoid angle ($p<0.0001$). The sagittal coraco–glenoid angle has not been investigated before but, as discussed, is similar to the novel index of Porter et al.¹⁶ The axial coraco–glenoid angle was smaller in the subscapularis tear group, which is in keeping with the original description of Gerber et al.⁶

The description by Gerber et al.⁶ of the subcoracoid space suggested that, for a given coracoid overlap, a small axial coraco–glenoid angle would result in more subcoracoid impingement. We did find a strong correlation between the two values within each group. However, we could find no difference between groups, which suggests that this relationship cannot be used to predict the presence of a subscapularis tear on MRI.

The limitations of the present study are its retrospective nature and relatively small numbers, although subgroups of previous studies that specifically analyze subscapularis tears are of similar size.^{8–10} There is a significant age difference between the two groups because shoulder instability surgery is predominately performed at a younger age.²¹ There is potential that lack of bony and soft tissue constraint to anterior translation may affect a shoulder requiring stabilization.

This may artificially decrease the anterior coraco–humeral distance. However, we consider this unlikely given that the defect would generally be antero–inferior. The measurements have yet to be correlated to treatment such as coracoplasty, although the aim was to identify whether positive correlations exist between coracoid morphology on MRI and subscapularis tears. Based on this, it is our current practice to perform a coracoplasty in the setting of a patient with a subscapularis tear and a sagittal coraco–glenoid angle of less than 60°.

Lastly, there has been a recent publication regarding a difference in the decrease in axial coraco–humeral distance when considering if the subscapularis tear is acute and traumatic versus chronic and degenerate.²² Balke et al.²² found that the only tears with a axial coraco–humeral distance <6 mm in their series were chronic tears, with no definable traumatic event. In their series, they found that the average axial coraco–humeral distance was 8.6 mm in chronic tears compared to traumatic tears having an average axial coraco–humeral distance of 10.2 and 10.4 in normal controls. We were unable to separate a subgroup with acute traumatic tears to sub-analyze.

Conclusions

This is the first study to comprehensively assess a range of coracoid indices on MRI and their association with arthroscopically proven subscapularis tears. We have identified the sagittal coraco–humeral angle, a new index, as having a significant association with these tears. There was a difference between groups in the axial coraco–humeral distance; however, we consider the difference is too small to be clinically useful. A cut-off of <6 mm was rarely seen in our sample. We feel that this is valuable information and supports the largest series in the literature in that a 6-mm cut-off may not be valid.¹⁰ There was a correlation between a narrow subcoracoid space in the sagittal plane and subscapularis tears. The static measures of coracoid morphology, measured solely within the scapula anatomy, are different between the case and control groups. This suggests an association between inferior projection of the coracoid and subscapularis tears, although we cannot assume this is causal. This is in keeping with previous studies.^{7,14} We have changed our practice to consider coracoplasty in cases with a sagittal coraco–humeral angle of less than 60°, representing the inferior projection of the coracoid potentially associated with coracoid impingement on the upper subscapularis tendon. These static measures may provide a basis for future studies of treatment effect as the sagittal measures have the advantage of being identifiable on MRI in a clinical setting.

Acknowledgements

The authors wish to thank Dr Steven Lane, Mr Ryan Khan and Dr Jane K Mills for their statistical assistance. This paper has been presented previously at the International Congress on Shoulder and Elbow Surgery (ICES), in Jeju Korea in May 2016. It also has been presented at the Shoulder and Elbow Surgeons of Australia (SESA) in August 2016.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The lead author receives institutional support from De Puy Synthes towards a research fellowship and statistician. No other authors, or their immediate families, receive any financial remunerations.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethical Review and Patient Consent

A negligible risk ethics proposal was accepted by our institutional review board (HREC 15/118).

Level of evidence

Level III: diagnostic study

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