A Novel MRI Measurement for Analysing Coracoacromial Morphology

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AIMS: Extrinsic factors of subacromial impingement of the shoulder can be potentially characterised by the angle between the acromion and coracoacromial ligament. A retrospective study was designed to test a novel angle measurement method for a potential new diagnostic tool.

PATIENTS AND METHODS: The landmarks and outcome measures were determined on sagittal cuts of default 1.5 T MRI scans. Two independent observers made the measurements on 50 annotated images of a cohort of healthy and young individuals.

RESULTS: The mean acromial-coracoacromial ligament (ACAL) angle was 129.8 degrees, (SD 10.0). The two independent measurements and a repeated one were compared for testing inter- and intra-observer reliability. Measurement of ACAL showed high internal consistency and strong measurement agreement between observers (Cronbach’s alpha values: 0.88, 0.86 and 0.94; Intraclass correlation coefficient values: 0.78, 0.75, 0.88). However, a statistically significant difference (p=0.035) was found on the retest measurement (1st to 2nd) of the same observer, despite the little difference (1st to 3rd p = 0.78; 2nd to 3rd p = 0.75) in inter-observer relation on paired sample t-test.

CONCLUSIONS: The measuring error came from poor definition of the landmarks on standard 3 mm slice thickness MRI scans. Altered scanning sequences with thinner slices might provide more details of the structures, improve reliability, and prove to be a clinically useful measure in a future prospective study.

KEY MESSAGES: ACAL measurement was not sufficiently reliable when performed on a default plane MRI scan; however, an altered scanning method might provide better visualisation and higher definition of the structures and could improve intra-observer reliability in further studies.

Key words: Arch, coracoacromial; Ligament; Angle; Subacromial; Impingement

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Legend

ACAL: acromion-coracoacromial ligament angle; CAL: coracoacromial ligament length; Acrm: Acromion length; Hypot: Hypotenuse length; Glen: Glenoid supero-inferior diameter; spur:
acromial spur in mm; Acrm shape: acromial morphology according to Bigliani and Vararth and Monu classification; SSP outlet: supraspinatus outlet area; Normalised: the SSP outlet area/glenoid height

INTRODUCTION

Impingement syndrome is a common cause of shoulder pain with an annual incidence of between 0.9 and 2.5% and with a lifetime prevalence from 6.9% to 66.7% in the general population worldwide[1]. Shoulder pain was the third most common musculoskeletal condition reported in primary care in 2005 and about 1% of the adult population presented with new onset shoulder pain. The majority (70%) of them related to rotator cuff pathology[2].

With the advent of magnetic resonance imaging, it is now possible to examine soft tissue changes and to define the three-dimensional anatomy of the coracoacromial arch without using radiation. Several studies found magnetic resonance imaging (MRI) scans to be reliable, sensitive and specific to detect rotator cuff tears and impingement-related changes, such as the distortion of the coracoacromial arch[3-4]. The coracoacromial arch anatomy on MRI has been described and various studies published with comparisons of differences in the subacromial space on MRI between symptomatic and asymptomatic cohorts[5-8]. Most of the studies required computerised analysis and, therefore, are not reproducible in everyday clinical settings, unlike the acromial-coracoacromial ligament (ACAL) angle, which has potential for routine clinical use. This present study explored the use of MRI scans to identify extrinsic causes of subacromial impingement, which might potentially serve as a diagnostic tool for shoulder impingement and aid surgical decision making. Additionally, this feature would potentially provide further details for understanding the pathogenesis of shoulder impingement syndrome and rotator cuff disease. This study aimed to quantify the anatomical appearance of the coracoacromial arch on MRI scans via measurements using recognisable landmarks.

METHODS AND MATERIALS

This specific measurement method has not been published previously and owing to its novelty the precise technique was defined and its inter- and intra-observer reliability were determined during this study. Sample size was calculated using a prospective power calculation. A similar previously published study was used as an example. Roidis et al. (2009) measured the supraspinatus outlet area on MRI scans in two cohorts of patients[9]. The mean outlet area was 577 mm² in asymptomatic young patients and 481 mm² in rotator cuff deficient adults. The mean difference of 96 mm² was significant, (p = 0.036). Using the frequencies of the above publication, a Chi-square table was constructed by an independent statistician and it was found that 50 patients were required in each arm of the study to obtain statistical power of 80% at an alpha value of 0.05. Measurements were then taken on 50 annotated, previously performed MRI images from the archive of the Hospital’s Radiology Department. The study used asymptomatic and rotator cuff deficient cohorts of patients to meet the original aims of the research. No patient identifiable data was used and no patients were physically involved in the study. For confidentiality purposes, the images were annotated, and were listed and identified by their unique hospital 7-digit PAS number (Patient Administration System, NHS IT Framework), which was unrelated and unlinked to any other identifiable data. The list and images were stored in a separate encrypted file in the radiology department’s PC for further reference until the study was completed and then it was deleted. This file was accessible only to the research team members. The study was registered at the hospital’s research and development department and via the Integrated Research Application System (IRAS). Favourable ethical opinion was given by the Health Research Authority’s East of England National Research Ethics Service (NRES) Committee (Project ID 127015, REC reference 14/EE/0047). The study conformed to the ethical principles outlined in the Declaration of Helsinki.

MRI scan images were produced by two 1.5 Tesla scanners, Phillips Intera Archieva and Siemens Aera, in the Radiology Department of the Trust. The images were then uploaded and stored in Picture Archiving and Communication System (PACS). This software was also used for the measurements (Centricity Enterprise TM, GE Healthcare Ltd) and is a popular clinical tool in assessing radiological images[10]. The researchers aimed to formulate this new measurement method for use in everyday clinical practice and this warranted testing on PACS, which by default provided all the necessary electronic measuring tools, for example, angle and distance measurements. Hence, the researchers believed that testing the method in a real clinical situation added extra value to the study. The study was performed on standard hospital PCs (Dell GX755 Desktop PC 17” LCD Monitor).

In order to reduce the confounding factor of age, young patients’ preoperative annotated MRI scans (between 18-25 years of age, with an average age of 22 years) were used for this phase of the study, hypothesising that the coracoacromial arch would lack degenerative changes. The images, obtained between 09/10/2012 and 30/09/2013, were quasi-randomly selected from the hospital’s Radiology Department database according to date of birth and orthopaedic history in the radiology reports. The most common indication for the MRI scan was shoulder instability and the majority of the scans were MRI arthrograms. The authors stipulated that the ACAL angle should not be affected by the small amount of intra-articular contrast agent (gadolinium). Sixty-two images were selected, irrespective of gender, race, dexterity, occupation, area of living, social circumstances, recreation or sport activity, health or co-morbidities. By gender, 50 male and 12 female patients’ MRI scans were collected with an approximate sex ratio of 4:1. Males were over-represented in the sample compared to the previously published ratio of 1.8:1[11]. The high male/female ratio could be explained by the high incidence of sport injuries in the catchment area where rugby was popular. In order to reduce other confounding factors, certain conditions were excluded, such as fracture, septic arthritis, tumour, previous acromioplasty, previous rotator cuff reconstruction, or other surgery that had left an implant in the area of interest.

According to inclusion and exclusion criteria 62 shoulder MRI scans were selected, comprising 10 plain MRI scans and 52 MRI arthrograms. Twenty scans were excluded: five had fractures, four were poor quality, seven had previous surgery, two had os acromiale and two scans were not accessible. Five additional MRI scans were available that had been performed on the contra-lateral shoulders of the same patients and three more from two patients who had repeated MRI scans on the same joint in various years. In addition, eight more available image-sets were included resulting in a total of 50 MRI scans collected for the study. To reduce ascertainment bias, the measurements were carried out blind and independently by two clinical research fellows (Observer A and B) who were an experienced orthopaedic trainee and trained orthopaedic surgeon, respectively. Both were familiar with the PACS software. Observer B repeated the measurements on all 50 MRI scans after a 2-week
washout period. This washout period was used to reduce recall bias. The 50 MRI scans were then reviewed three times by the two observers: observer “B” did the first (M1) and second (M2) repeated measurements and observer “A” did the third (M3) countermeasurement.

The ACAL angle was established and defined among well recognised bony landmarks and the line of the coracoacromial ligament (CAL) on T2 weight sagittal MRI scan images, specifically on cuts where the coracoid tip just appeared (Figure 1 and Figure 2). The vertex of the angle was on the anterior margin of the acromion where the CAL was inserted. The anterior side was along the CAL and ended at the ligament’s origin on the coracoid process. The posterior side was drawn along the under-surface of the acromion and ended at its posterior end. Then the two sides were connected with a line forming a triangle and were used as the hypotenuse. In order to test the measurement reliability, secondary outcome measures were established. The length of the sides (CAL and acromion) and the hypotenuse, and the territory of the triangle were calculated. The latter was believed to correspond to the supraspinatus outlet area[8]. It was then normalised with glenoid height in order to adjust the values to an individual basis. Glenoid height was believed to correspond to the patients’ overall body characteristics and it was defined as its supero-inferior diameter, a distance between the base of the coracoid at the proximal pole and the base of the scapular wing at the distal pole of the glenoid rim. When acromial spurs were observed, their extensions from the acromial plane were measured at a right angle (Figure 1b). These measurements provided continuous data for further statistical analysis. The observed acromia were classified according to Bigliani’s concept[11]. The following categories were used: type I, as flat; type II, as curved; and type III, as hooked shaped in cross section. For describing a convex shaped acromion, a type IV category was used according to Vanarthos and Monu classification[12]. A plan was made to conduct another study using participants with symptomatic shoulders and then acromial configuration would have been relevant, hence the rationale for distinguishing acromia type. These categorical data were collected in order to complete the analysis with previously stipulated features of impingement[13-14].

**Figure 1 a+b:** Examples for ACAL angle measurement. The landmarks: undersurface of acromion, the coraco-acromial ligament and its acromial and coracoid attachments, and the posterior edge of acromion. These points form a triangle, representing an area of a cross section of the subacromial space.

**Figure 2 a+b:** The ACAL angle measurement landmarks on plain x-ray and sagittal MRI scan image of the same shoulder joint. It is noticeable the plane of the sagittal MRI slice cuts through the ligament in an angle as it represented with the purple line. It may explain the ligament segmental appearance on the image.

Altogether 150 measurements were taken and 8 outcome measures were collected each time. The three sets of measurements were then compared for inter-observer and intra-observer reliability. For the statistical analysis IBM®SPSS® Statistics Version 22 software was used (SPSS Inc., Chicago, IL). Distribution, maximum and minimum values of the range, the mean with a 95% confidence interval and standard deviation (SD) of each outcome were calculated using descriptive statistical analysis. Relative reliability was calculated using the intraclass correlation coefficient (ICC) and Cronbach’s Alpha. Absolute reliability was calculated with a paired samples t-test. The paired sample correlation, mean difference, standard deviation of the differences (diff SD), standard error of the mean difference (SEM), and p value were calculated. Statistically significant changes were accepted at $p < 0.05$. Cronbach’s alpha was considered as acceptable between 0.60-0.69, good if between 0.70-0.89 and excellent if above 0.90. The ICC was interpreted as moderate agreement between 0.50-0.69, strong agreement between 0.70-0.79, and almost perfect agreement above 0.80[15-16].

**RESULTS**

The mean ACAL angle was 129.7° (95% CI = 128.5° – 131.7°; SD 10.03). The range was from 105.6° to 154.9° and the distribution was Gaussian. Comparing the ACAL angle measurements (M1 to M3; M2 to M3; M1 to M2) showed high internal consistency (Cronbach’s alpha 0.88, 0.86 and 0.94) and strong measurement agreement (ICC of 0.78, 0.75, and 0.88). Despite the high correlations, the
paired sample analysis showed a significant mean difference ($p = 0.035$) in the measured angles when comparing the first (M1) and repeated (M2) measurements, indicating systematic bias across repeated measures. The measured angles were closer together ($p = 0.15$ and $p = 0.91$) in the inter-observer relations, namely the first to third and second to third measurements, which were reliable. Scatter plots (Graph 1, Graph 2, Graph 3) demonstrated a good relative relationship among the arms, but systematic error of the measurements. Bland-Altman plots (Graph 4, Graph 5, Graph 6) were generated and all three plots showed symmetric and wide distribution, with no particular pattern, suggesting no systematic bias, but systematic error of measurements as confidence intervals were in a wide range.

The paired mean differences were only a few degrees (M1 vs M3 1.38°, M2 vs M3 0.11°, M1 vs M2 1.5°) and the range of the differences for the paired angles was from 0.1° to 20.6°. The SD of the differences were 4.8° (M1 vs M2), 6.7° (M1 vs M3) and 7.1° (M2 vs M3) and it was expected the difference between the measurements of two different observers would be within the range of +/- 1.96 SD, namely from 9.4° to 13.9° and there was 95% chance for two separate measurements would differ by +/- 12.1°. The Bland-Altman plots showed the level of agreement was too wide a range (+/- 12.1°) for measuring potentially less than 10° pathological alteration on the MRI scans in spite of the very little difference between the means of the measurements. The secondary outcome measures were less reliably measured, as some of them had poor correlations and others had significant mean differences across measurements (Table 1).

**DISCUSSION**

The main aim of the present study was to develop a novel measuring method for the coracoclavicular arch on standard MRI scans of the shoulder and test its intra- and inter-observer reliability. Two observers measured the angle of the acromion to the coracoclavicular...
ligament (ACAL angle) along with other secondary measures. The ACAL angle might have been unrelated to the actual size of the ligament, the acromion or the coracoid process, and as the ligament is connected to two fixed points of the bony scapula, it was considered as constant. It appeared to be well measurable and the mean difference among the measured angle values was statistically non-significant between observers, but significant across the repeated measurements of observer B. The systematic error might have been from various causes.

Graph 1 Scatter plot representing inter-observer correlation.

Graph 2 Scatter plot representing inter-observer correlation.

Graph 3 Scatter plot representing intra-observer correlation.

Graph 4 Bland-Altman Plot of ACAL angle M1 and M2 with Mean Diff 1.5° 95%CI -8.026° – 11.01° (intra-observer reliability).

Graph 5 Bland-Altman Plot of ACAL angle M1 vs M3 measurement with Mean Diff 1.38° 95% CI -11.75°- 14.5° (inter-observer reliability).

Graph 6 Bland-Altman Plot of ACAL angle M2 vs M3 measurement with Mean Diff -0.11° 95% CI -14.3°-13.8° (inter-observer reliability).
Table 1 Summarised reliability test results. Green fields are representing the intra-observer reliability results. White fields are inter-observer results. Outlying results are highlighted with red.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Relative Reliability</th>
<th>Absolute Reliability</th>
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<tbody>
<tr>
<td></td>
<td>Cronbach's Alpha</td>
<td>Intraclass Correlation Coefficient (ICC)</td>
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<tr>
<td>ACAL M1M3</td>
<td>0.876</td>
<td>0.78</td>
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<tr>
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<tr>
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<tr>
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<td>Normalised M1M2</td>
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the ligament on dynamic ultrasound scan are reported, which suggests its function as a restraint and also with a role in proprioception\cite{22}. It is also reported the ligament can reform or regenerate after surgical transection, suggesting its functional importance as an anatomical structure\cite{23-24}. The altered plane MRI scan may reveal further morphological features to aid understanding of the role of CAL in impingement.

**Figure 3 a+b**: The desired plane of sagittal MRI scan visualising the coraco-acromial arch, including the full length of CAL and cross section of the acromion.

### CONCLUSION

Measurement of the angle of the ligament to the acromion (ACAL angle) was hypothesised to be relevant so that a steeper angle decreases the subacromial space, leading to increased contact and pressure of the above-mentioned structures. Even though the ACAL angle was measured with good correlation between the observers, within the first and repeated observations the measured values were significantly different. An altered scanning method might provide better visualisation and higher definition of the structures and could improve intra-observer reliability in further studies.

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