Acta Med. Okayama, 2013
Vol. 67, No. 6, pp. 377–383

Acta Medica Okayama
http://escholarship.lib.okayama-u.ac.jp/amo/

Original Article

Coverage of the Humeral Head by the Coracoacromial Arch: Relationship with Rotator Cuff Tears

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The pathogenetic roles of the coracoacromial arch in the development of rotator cuff tears are still controversial. This study compared the anteroposterior coverage of the humeral head by the coracoacromial arch between shoulders with and without full-thickness rotator cuff tears. Forty-two shoulders from 21 embalmed cadaveric specimens were macroscopically examined. Specimens were divided into 2 groups: shoulders with full-thickness cuff tears (tear group) and those with intact cuff tendons (normal group). The coverage angle of each component of the coracoacromial arch was measured using true lateral photographs. We also measured the angle of the total arc of the coracoacromial arch, as well as the angle of the anterior acromial projection. These data were compared between the tear group and the normal group. Although no significant differences were observed in the total arc of the coracoacromial arch between the groups, the tear group had significantly less coverage by the coracoacromial ligament than did the normal group ($p < 0.05$). Moreover, greater anterior acromial projection was observed in the tear group ($p < 0.05$). These results suggest that greater coverage of the bony structures on the rotator cuff may correlate with the development of rotator cuff tears.

Key words: rotator cuff tear, coracoacromial arch, humeral head, anatomy

The coracoacromial arch consists of the coracoid process, coracoacromial ligament, and acromion. This arch covers the rotator cuff tendons, which wrap around the humeral head. Several studies have been conducted to investigate the pathogenetic roles of the coracoacromial arch in the tearing of rotator cuff tendons because of the close anatomic relationship between these structures. The shape or the size of the acromion has been of great interest to many researchers. In 1972, Neer [1] pointed out the relationship between acromial morphology and subacromial impingement syndrome. Bigliani *et al.* [2] categorized the shape of the acromion into 3 types (flat, curved, and hooked) in the sagittal plane. They reported that the hooked-type acromion was associated with rotator cuff tears [2–4], a proposal which was later confirmed by other researchers [5, 6]. More recently, Nyffeler *et al.* [7] and Torrens *et al.* [8] reported that the high coverage of the acromion in the coronal plane may also be associated with tearing of the rotator cuff tendon.

Regarding other components of the coracoacromial arch, Gerber *et al.* [9] reported that the coracoid process also played an important role in the pathogen-

Received April 25, 2013; accepted July 18, 2013.
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esis of subscapularis tendon tears. However, those authors investigated only the bony components of the coracoacromial arch in their studies. According to the biomechanical study, contact was observed between the coracoacromial ligament and the rotator cuff tendons during all shoulder motions in normal subjects [10]. The results of that study suggested that in addition to the bony structures, the coracoacromial ligament should be considered when investigating the pathogenetic roles of the coracoacromial arch in rotator cuff tears.

Moreover, most of the previous authors dealt with the acromial spur as part of the acromion in their measurement of acromial coverage. To clarify the true relationship between the acromial morphology and the rotator cuff lesion, we suspected that the influence of the acromial spur should be excluded. Against this background, we attempted to investigate the coverage of the rotator cuff tendons by both the bony and ligamentous components of the coracoacromial arch in cadaveric shoulders. We excluded the influence of the acromial spur and hypothesized that the undersurface of the coracoacromial arch constituted a part of a circle in the sagittal plane, which enabled us to quantify the amount of its coverage of the humeral head with the central angles. The purpose of this study was to determine the anteroposterior coverage of the humeral head by the coracoacromial arch in shoulders with and without full-thickness rotator cuff tears.

Materials and Methods

Preparation of the specimens. Forty-two shoulders from 21 embalmed cadaveric specimens were macroscopically examined. The mean age at death was 83 years (range, 70-94 years). We divided the specimens into 2 groups: shoulders with full-thickness cuff tears (the tear group, $n = 7$, or 17%) and those with intact cuff tendons (the normal group, $n = 35$, or 83%). According to the Cofield classification [11], the 7 shoulder in the tear group included 2 small tears (< 1 cm), 1 medium tear (1 to < 3 cm), 1 large tear (3 to < 5 cm), and 3 massive tears (≥ 5 cm). On macroscopic examination, no specimens exhibited partial-thickness tears in the present series.

To expose both the coracoacromial arch and the rotator cuff tendons, we removed all the periscapular muscles (the deltoid, trapezius, pectoralis major and minor, levator scapulae, rhomboid major and minor, and serratus anterior muscles). Care was taken not to damage the rotator cuff muscles or the coracoacromial arch. After dissection, each specimen was mounted on a custom-designed shoulder-positioning device. Both the superior and the inferior angles of the scapula were fixed using clamps, and they were placed on a vertical line (Fig. 1). A digital camera was then

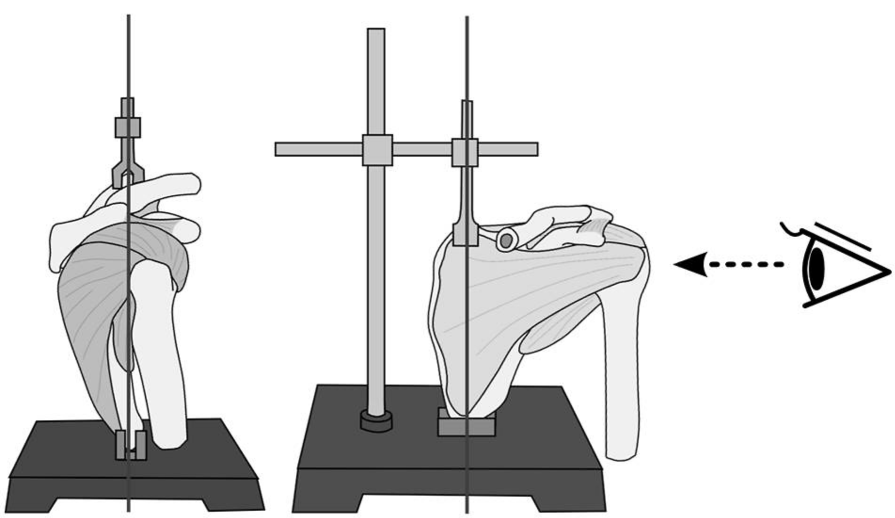

Fig. 1 Mounting of specimens on the custom-designed shoulder-positioning device. The scapula was mounted on the device. Both the superior and the inferior angles of the scapula were fixed using clamps, and they were placed on a vertical line in the sagittal and coronal planes. True lateral photographs of the shoulder joint were then obtained.

placed at the same height of the center of the humeral head, and a true lateral photograph of the shoulder joint was obtained.

Measurements of the coracoacromial coverage. On the lateral image of the cadaver shoulders, we drew a circle fitted to the undersurface of the coracoacromial arch, and its center was determined on the photograph (Fig. 2). A horizontal line passing through the center of the circle was identified as the equator. From the center of the circle, we drew the following four lines using computer software: to the posteroinferior edge of the acromion (Ai), to the anterosuperior edge of the acromion (Aa), to the posterior border of the coracoid process (Cs), and to the inferior border of the coracoid process (Ci). Aa was set on the anterosuperior aspect of the acromion to eliminate the influence of the osteophyte that usually exists at the anteroinferior aspect of the acromion [12]. Then, we measured the angles between each line, and the coverage of the rotator cuff tendons by the acromion (Ai–Aa), the coracoacromial ligament (Aa–Cs), and the coracoid process (Cs–Ci) was determined (Fig. 2A).

In the present study, we also measured the total arc of the coracoacromial arch (the angle between Ai and Ci; from the posterior edge of the acromion to the inferior edge of the coracoid process) and the anterior acromial projection (the angle from the vertical line to Aa) (Fig. 2B). The image-analysis software ImageJ (version 1.44p, National Institutes of Health, Bethesda, MD, USA) was used to measure each angle, which we then compared between the tear group and the normal group. We also determined the percentage of occupancy of each component of the coracoacromial arch (occupancy ratio) to clarify the proportion of the coracoacromial arch in each patient (Fig. 3). These parameters were also compared between the tear group and the normal group.

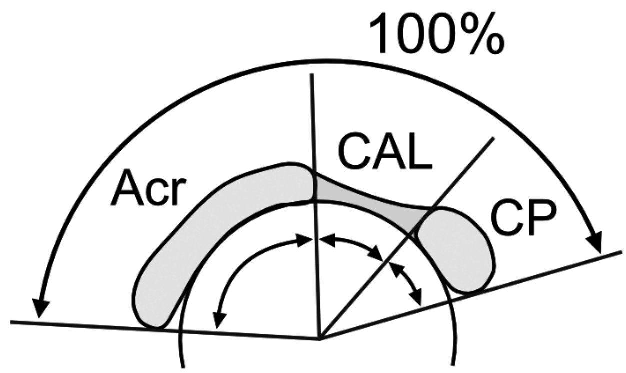

Fig. 3 The occupancy ratio of each component of the coracoacromial arch. Acr, acromion; CAL, coracoacromial ligament; CP, coracoid process.

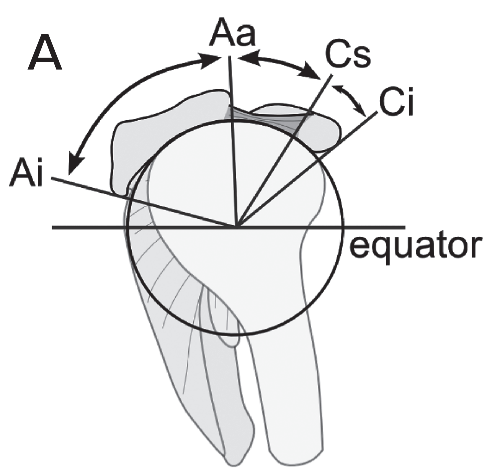

Fig. 2 Measurement of the parameters. (**A**) The circle and lines were drawn using computer software. The equator line was identified as the horizontal line passing through the center of the circle. Ci, the inferior edge of the coracoid process; Cs, the superior edge of the coracoid process; Aa, the anterosuperior edge of the acromion; Ai, the posteroinferior edge of the acromion. (**B**) The anterior acromial projection (AAP) was determined as the angle between the vertical line and Aa. The AAP had a positive value when the Aa was anterior to the vertical line and a negative value when the Aa was posterior to the vertical line.

Statistical analyses. Statistical analysis was performed using StatMate III statistical software (version 3.16; Atms Co., Tokyo, Japan). The measured angles were compared using Mann-Whitney's U-test. A *p*-value less than 0.05 was considered significant.

Results

The mean coverage angle by the acromion was 91.1 degrees in the tear group and 84.3 degrees in the normal group (Table 1). The tear group showed relatively greater acromial coverage than that of the normal group, although the difference was not significant. The mean coverage angles by the coracoacromial ligament in the tear group and the normal group were 35.1 degrees and 43.1 degrees, respectively (Table 1). The difference between the 2 groups was significant ($p < 0.05$). However, the mean coverage angle by the coracoid process was almost identical in the 2 groups: 31.1 degrees for the tear group and 32.2 degrees for the normal group (Table 1). Fig. 4 shows photographs of representative specimens with and without a cuff tear.

In the present series, the mean total arc of the coracoacromial arch was 157.3 degrees in the tear group (Table 1). Interestingly, it was almost identical for the normal group (mean, 159.6 degrees), with no significant difference between the groups. The anterior acromial projection was 6.7 degrees in the tear group and −2.0 degrees in the normal group (Table 1). The acromion showed significantly greater anterior projection in the tear group than in the normal group ($p < 0.05$).

The occupancy ratio of each anatomical structure in the coracoacromial arch is shown in Table 2. The acromion occupied 57.9% of the coracoacromial arch in the tear group, which was significantly greater than the coverage in the normal group (53.1%; $p < 0.001$). The tear group also had a significantly smaller occupancy ratio for the coracoacromial ligament (22.3%) compared to that of the normal group (26.7%; $p < 0.05$). The occupancy ratio of the coracoid process was almost identical in both groups (19.9% and 20.1%, respectively).

Discussion

Previous studies have demonstrated that the greater the anterior projection of the acromion, the higher the incidence of rotator cuff tears [13, 14]. In 2001, Lee *et al.* [13] reported that an anterior tip of the acromion located beyond the 12 o'clock direction of the superior glenoid may contribute to the pathogenesis of a rotator cuff tear. Unfortunately, those authors did not exclude the presence of osteophytes of the anterior acromion in their analysis. To clarify the true influence of the acromial morphology on the pathology

Table 1 The data of the measured parameters

	Number	Acromion	Coracoacromial ligament	Coracoid process	Total arc of coracoacromial arch	Anterior acromial projection
Tear group	7	91.1 +/ -13.4	35.1 +/- 9.7	31.1 +/- 6.2	157.3 +/- 17.4	6.7 +/- 11.2
Normal group	35	84.3 +/- 6.7	43.1 +/- 12.2	32.2 +/- 5.2	159.6 +/- 11.7	−2.0 +/- 7.3
p		ns	< 0.05	ns	ns	< 0.05

Table 2 The data of the occupying ratio of each structures of the coracoacromial arch

	Number	Acromion (%)	Coracoacromial ligament (%)	Coracoid process (%)
tear group	7	57.9 +/- 4.1	22.3 +/- 5.3	19.9 +/- 4.5
normal group	35	53.1 +/- 5.9	26.7 +/- 6.6	20.1 +/- 2.7
p		< 0.001	< 0.05	ns

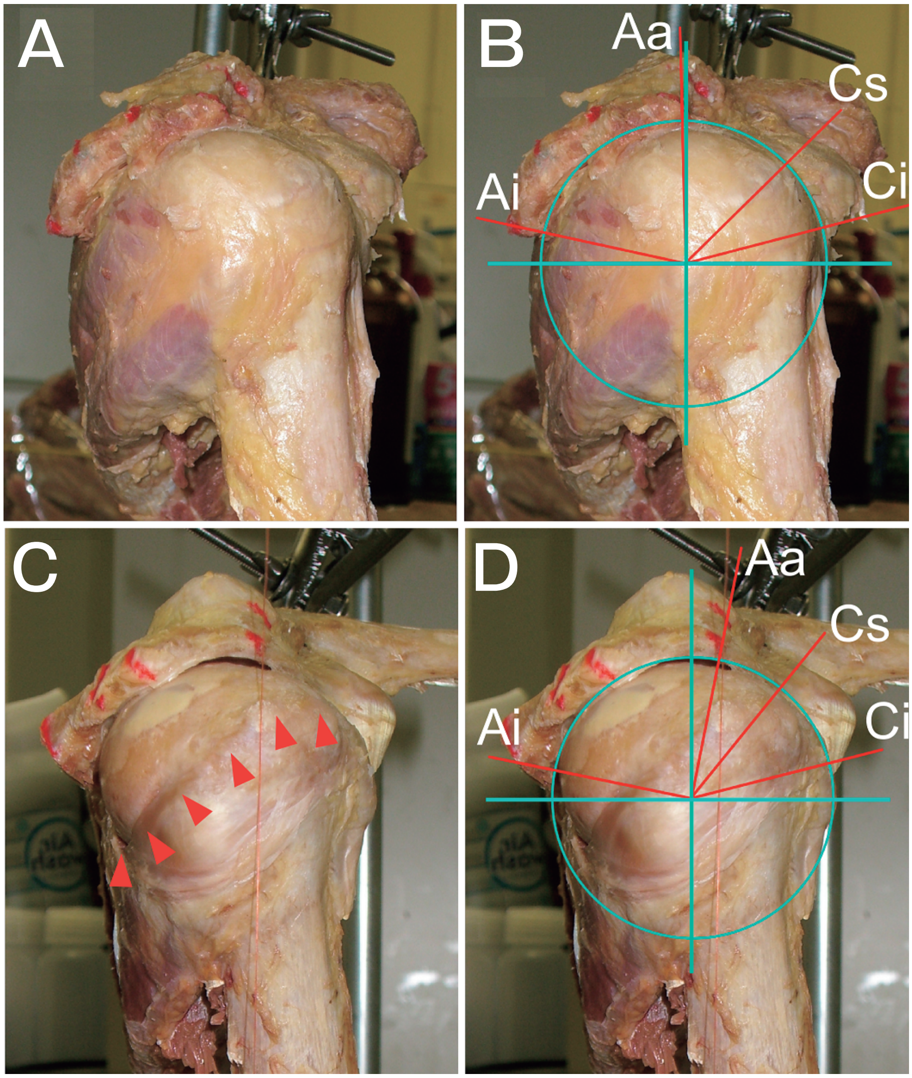

Fig. 4 The lateral views of right shoulders with and without full-thickness rotator cuff tears. (A, B) The shoulder without a cuff tear had less acromial coverage (between Ai to Aa) and longer coracoacromial ligament (between Aa to Cs). The anterior acromial projection had a negative value because the Aa was posterior to the vertical line. (C, D) The shoulders with a cuff tear had greater acromial coverage (between Ai to Aa) and a shorter coracoacromial ligament (between the Aa and the Cs). The supraspinatus and infraspinatus tendons were completely detached from the greater tuberosity (red arrowheads). The Aa was anterior to the vertical line, so the anterior acromial projection had a positive value. Aa, the anterosuperior edge of the acromion; Ai, the posteroinferior edge of the acromion; Cs, the superior edge of the coracoid process; Ci, the inferior edge of the coracoid process.

of the rotator cuff tendon, we excluded the influence of the acromial spur from the measurements in the present study, and we found that the anterior acromial projection was significantly greater in the tear group (6.0 degrees) than in the normal group (−2.1 degrees).

In the seven shoulders with rotator cuff tears, the original anterior edge of the acromion appeared to extend beyond the 12 o'clock position of the coracoacromial arch. As the anterior tip extends anteriorly, the acromion starts to resemble a hooked shape [13]. Bigliani [4] believed that a hooked acromion may cause subacromial impingement. Therefore, a greater anterior acromial projection may have affected the development or propagation of full-thickness rotator cuff tears in the present series.

To assess the original acromial morphology, the precise extent of the spur formation at this site must be determined. Several previous studies proposed that the osteophyte at the anterior edge of the acromion develops secondarily, reflecting various types of mechanical stress in the coracoacromial ligament [15–17]. Particularly in shoulders with large-to-massive rotator cuff tears, the humeral head tends to migrate toward the anterosuperior direction; this causes contact between the humeral head and the coracoacromial ligament. As a result of this phenomenon, various types of biomechanical stress (*i.e.*, compressive or tensile stresses) in the coracoacromial ligament become more evident, inducing the development of spur formation within the coracoacromial ligament. Such osteophytes are usually located only on the undersurface of the acromion, not on the superior surface of the acromion, because of the localization of the origin of this ligament [12].

Considering these findings, we decided to use the anterosuperior margin of the acromion as a landmark for drawing the line Aa to exclude the influences of spur formation. Thus, the extent of anterior acromial projection measured in the present study was not caused secondarily by the rotator cuff tear.

In the present study, we also investigated the occupying percentage of each structure in the coracoacromial arch. Although there were no significant differences in the total arc of the coracoacromial arch between the 2 groups, the tear group showed a greater occupancy ratio for the acromion and a lesser occupancy ratio for the coracoacromial ligament compared to the normal group. These results suggest that the percentage of bony tissue occupying the coracoacromial arch is related to the incidence of full-thickness rotator cuff tears. A large acromion in the sagittal plane may play some role in the development or propagation of full-thickness rotator cuff tears.

Several studies have focused on the relationship between the incidence of rotator cuff tears and the acromial morphology on radiographs [7, 8, 12, 18–20]. Among them, only Prato *et al.* [20] used lateral radiographs of the shoulder to assess acromial morphology. However, the relationship between anterosuperior acromial coverage and rotator cuff tears was not reported. In the clinical setting, the measurements obtained in the present study can be determined on a scapular-Y radiograph. The scapular-Y radiograph may have some differences compared with the photographs of this study, but the methodology of the current study can be used in clinical evaluations. Further prospective studies are required to determine the prognostic significance of anteroposterior coracoacromial coverage with respect to full-thickness rotator cuff tears.

Our study had several limitations. First, the number of cadaver specimens was limited. Although our findings showed that a greater anterior acromial projection is correlated with the incidence of rotator cuff tears, the sample size was limited. To gain statistical power of >0.80, the tear group needs 13 shoulders and the normal group needs 63 shoulders. A similar statement can be made about the occupancy ratio; >70 shoulders are necessary to gain a power of 80%. Second, partial-thickness rotator cuff tears were not observed in the present series. Bursal-side tears have been hypothesized to be related to the morphology of the acromion and the coracoacromial arch [21]. Third, the upward migration of the humeral head caused by the full-thickness rotator cuff tears may affect the measurements. In the present study, a complex of the proximal end of the humerus and the rotator cuff was considered to be the convexity covered by the concavity of the coracoacromial arch. Particularly in shoulders with global rotator cuff tears or cuff tear arthropathy, the convexity of the humeral head and rotator cuff becomes distorted. In such cases, the coverage by the coracoacromial arch may be altered by marked upward migration of the humeral head or destructive changes affecting the shoulder joint. Therefore, caution should be exercised when applying these findings to shoulders with massive rotator cuff tears.

In conclusion, shoulders with rotator cuff tears had a greater anterior projection of the acromion than did those with intact rotator cuff tendons. Compared to humeral heads with intact rotator cuff tendons, those with full-thickness rotator cuff tears demonstrated greater coverage by the acromion and smaller coverage by the coracoacromial ligament. Our results suggest that the greater anterior projection of the acromion contributes to the development or the propagation of rotator cuff tears.

Acknowledgments. We thank Professor Mari Dezawa and Dr. Jianlin Zuo for their support.

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