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ORIGINAL ARTICLE

The critical acromial point: the anatomic location of the lateral acromion in the critical shoulder angle

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Background: Acromioplasty has been proposed as a means of altering elevated critical shoulder angles (CSAs). We aimed to localize the critical acromion point (CAP) responsible for the acromial contribution of the CSA and determine whether resection of the CAP can alter the CSA to a normal range.
Methods: The CAP and 3-dimensional (3D) CSAs were determined on 3D computed tomography reconstructions of 88 cadaveric shoulders and compared with corresponding CSAs on digitally reconstructed radiographs. The position of the CAP was fluoroscopically isolated in 20 of these specimens and the resulting fluoroscopic CSA compared with the corresponding 3D CAP and 3D CSA. We investigated the CSA before and after a virtual acromioplasty of 2.5 and 5 mm at the CAP in specimens with a CSA greater than 35°.
Results: The mean CAP was 21% ± 10% of the acromial anterior-posterior length from the anterolateral corner. There was no difference between the mean 3D CSA and the CSA on digitally reconstructed radiographs (32° vs 32°, $P = .096$). No difference between the mean fluoroscopic CSA and 3D CSA was found (31° vs 31°, $P = .296$). A 2.5-mm acromial resection failed to reduce the CSA to 35° or less in 7 of 13 shoulders, whereas a 5-mm resection reduced the CSA to 35° or less in 12 of 13.
Conclusion: The CAP was localized to the anterolateral acromial edge and was easily identified fluoroscopically. A 5-mm acromial resection was effective in reducing the CSA to 35° or less. These data can guide surgeons in where and how to alter the CSA if future studies demonstrate a clinical benefit to surgically modifying this radiographic parameter.
Level of evidence: Basic Science; Anatomic Study; Imaging

Keywords: Critical shoulder angle; acromion; acromioplasty; computed tomography (CT); 3D CT reconstruction; digitally reconstructed radiograph; scapular anatomy

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Several radiographic parameters have been studied for their association with rotator cuff pathology. The acromial index, a radiographic ratio of the lateral acromial extension to the lateral extension of the humeral head relative to the glenoid, has conflicting studies suggesting it may[14,20,21] or may not[10] be related full-thickness cuff tears. Glenoid inclination is the measure of superior tilt of the glenoid articular surface, which

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has been associated with rotator cuff tears and risk of retear after repair.[6,8,11] The critical shoulder angle (CSA) was developed as a combination of the acromial index and glenoid inclination, measuring the angle between the line connecting the superior border with the inferior border of the glenoid and the line connecting the most lateral point of the acromion with the inferior border of the glenoid on a true anteroposterior (AP) radiograph.[18] High CSAs (>35°) have been associated with rotator cuff tears, whereas low CSAs (<30°) have been associated with glenohumeral osteoarthritis.[3,18,22] In the presence of superiorly tilted glenoids and/or a high CSA, the prevailing concept is that the deltoid force vector is directed more vertically, leading to proximal humeral translation. To preserve joint stability, the rotator cuff compensates, leading to increased strain on the tendons and subsequent rotator cuff pathology.[7,9,28] This increases the risk of rotator cuff injury and has been supported by several biomechanical studies.[15,18,29]

If the CSA truly influences the potential rotator cuff degeneration,[2-4,6,14,19,24] the ability to alter this parameter to an acceptable range may be beneficial. Several cadaveric studies have demonstrated the ability to change the CSA by both a standard anterolateral and direct lateral acromioplasty.[1,13] Both resection techniques influenced the CSA, yet the direct lateral acromioplasty had the largest effect on the CSA, suggesting the exact location on the acromion responsible for the radiographic CSA measurement is not fully understood.[1,13] The CSA references the most lateral aspect of the acromion on the true AP radiograph[18]; however, no study has specifically localized this radiographic reference point to the anatomic region on the acromion. The clinical significance of the lateral acromial overhang in an elevated CSA angle is unknown. If the surgeon desires to change the CSA to within an "acceptable" range, the exact anatomic region referenced on the radiograph could be resected to more accurately change the angle and avoid resecting bone not contributing to the CSA.

Therefore, the primary objective of this study was to determine the anatomic region on the lateral acromion measured in the CSA on plain radiographs, using 3-dimensional (3D) computed tomography (CT) shoulder reconstructions. We hypothesized that there would be no difference between the 3D CSA measured on CT reconstructions and the traditional 2-dimensional (2D) CSA measured on digitally reconstructed radiographs (DRRs). The secondary objectives were to investigate whether this lateral acromion anatomic region could be accurately located using fluoroscopy and to investigate whether the CSA could be reduced by virtual resection of only this anatomic region on the lateral acromion. We hypothesized that the lateral acromion could be accurately localized fluoroscopically and resection would reduce high CSAs (>35°) into the "normal" range (CSA >30° to <35°).

Materials and methods

A database of 68 cadaveric scapulae (25 pairs plus 18 individuals) from a previous study of CSA[25] was supplemented with 20 cadaveric specimens for experimental analysis (5 pairs plus 10 individuals). These 88 cadaveric shoulders (46 left, 46 female) with a mean age of 62 years (range, 26-101 years) had previously been dissected by an orthopedic surgeon and verified to be free of any significant glenohumeral or rotator cuff pathology.

Three-dimensional CT and DRR protocol

All specimens underwent a glenohumeral CT scan using a Siemens Sensation scanner (Siemens, Erlangen, Germany). Image data were acquired with a 130-kV tube voltage, 512 × 512 acquisition matrix, 1.0-mm slice thickness, 0.75 pitch, and 170–milliamperage-seconds baseline tube current. Three-dimensional reconstructions were then made using Amira (version 5.4; Visage Imaging, San Diego, CA, USA) and aligned according to a scapula-based coordinate system,[12] where the origin was defined as the center of the best-fit circle of the inferior glenoid (C); z-axis, the line from the point where the scapular spine intersects the medial border of the scapula (SM) to C (+lateral); yz-plane, the plane defined by C, SM, and the most inferior point on the inferior scapular angle; and x-axis, normal to the yz-plane (+anterior) (Fig. 1). To create a true AP view of the glenoid as described previously,[27] each scapula was rotated about the y-axis, being the cross product of the x- and z-axes directed superiorly, to correct for the respective glenoid version. In this controlled viewing perspective resembling a clinical AP radiograph, DRRs were generated in Amira.

Morphometric measurements

DRR images of all 88 shoulders were imported to ImageJ (National Institutes of Health, Bethesda, MD, USA), and the CSA was measured according to Moor et al[18] as the angle between the most lateral point on the acromion and the inferior glenoid margin and superior glenoid margin (Fig. 2, *A*).

The aligned 3D reconstructed CT scans of all specimens were then imported in 3-matic (Materialise, Leuven, Belgium) for further analyses. To re-create a 3D CSA measurement, the superior and inferior poles of the glenoid were marked over the entire glenoid width, as was the entire lateral acromion. These marked anatomic structures of interest were then separated as independent parts. This allowed us to analyze the anatomic segment of interest independently and in an unbiased manner without changing the spatial position of the segment on the scapula. The most lateral point of the acromion (termed the "critical acromion point" [CAP]), inferior glenoid, and superior glenoid were acquired in an automated fashion using the extrema function. This function within the software calculates the most extreme point (maximum or minimum) on the studied anatomic structure along a predefined axis. The most lateral point of each segment of interest could then be acquired automatically by asking for the maximum point along the scapular axis (z-axis) for the respective segments: acromion and superior and inferior glenoid poles. The angle between the CAP, inferior glenoid, and superior glenoid represented the absolute 3D CSA. This angle was transformed into a 2D angle by projecting the absolute 3D CSA to the yz-plane (true 3D CSA), being the plane that determined the true AP view (Fig. 2, *B* and *C*).

The position of the CAP was assessed as a percentage of the linear AP distance (x-axis) to the anterolateral corner and posterolateral corner of the acromion, respectively, as a function of the AP acromial length ([a/ab] × 100, in which "a" is the distance from the anterolateral corner of the acromion to the critical acromion point,