The Relationship between Critical Shoulder Angle and In-Vivo Glenohumeral Joint Motion in Healthy and Pathologic Shoulders

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Introduction: Rotator cuff pathology is a common condition that is associated with pain, functional deficits and a decreased quality of life. The etiology of this condition is not well understood, but it has recently been shown that rotator cuff tears are associated with the critical shoulder angle (CSA), a morphological parameter that takes into account both glenoid inclination and lateral extension of the acromion [1] (Fig. 1). Briefly, it has been shown that patients with rotator cuff tears have a significantly higher CSA than individuals with healthy shoulders [1]. This finding led to the hypothesis that a higher CSA may be associated with overloading of the supraspinatus and subsequent superior migration of the humerus, which has been supported by cadaveric experiments and computer simulations [2, 3]. However, the relationship between CSA and glenohumeral joint motion has not been assessed under in-vivo conditions. Therefore, the objective of this study was to assess the relationship between CSA and in-vivo glenohumeral joint motion. We hypothesized that a higher CSA would be associated with a more superiorly located humeral position.

Methods: Following IRB approval, measures of CSA and in-vivo glenohumeral joint motion were acquired in 84 shoulders from a convenience sample of subjects enrolled in on-going studies. These data were acquired from two subject populations: patients with rotator cuff pathology and in volunteers with normal shoulder function. The rotator cuff tear (RCT) group consisted of 36 shoulders from 22 patients who had undergone unilateral surgical rotator cuff repair, 5 patients enrolled in physical therapy because of a documented symptomatic rotator cuff tear, and 9 patients with a documented asymptomatic rotator cuff tear (average age: 64±10). The healthy control group (CTL) consisted of 47 shoulders from 47 subjects (age: 39±17) who had normal shoulder function and a documented intact rotator cuff. To assess glenohumeral joint motion, biplane x-ray images were acquired during coronal-plane abduction for each subject. The 3D positions of the humerus and scapula were tracked from the biplane x-ray images using an accurate (±0.4 mm, ±0.5°) CT model-based technique [4]. Using these data, the average glenohumeral joint contact center - i.e., the average center of contact of the humerus on the glenoid - was calculated for each trial and expressed in terms of its superior/inferior (S/I) and anterior/posterior (A/P) position relative to the glenoid. To assess CSA, we used subject-specific CT-based bone models to determine the angle between a line connecting superior and inferior margins of the glenoid and a line connecting the inferior margin of the glenoid to the lateral border of the acromion [1] (Fig. 1). CSA was compared between the two subject groups with a t-test and the relationships between the S/I contact center and CSA were determined with linear regression and correlation. Significance was set at p≤0.05.

Results: The CSA was significantly greater in patients with a documented rotator cuff tear (RCT: 36.9 ± 5.0º) compared to the subjects with healthy shoulders (CTL: 34.5 ± 4.7º, p=0.03). However, the association between CSA and average S/I joint contact center was contrary to what was expected (Fig. 2).
2). Specifically, there was a significant negative association between the CSA and average S/I joint contact center in CTL subjects \((r=-0.30, \ p=0.04, \ \text{Fig. } 2)\), indicating that a higher CSA was associated with the humerus positioned more inferiorly on the glenoid during shoulder abduction. There was also a negative association between the CSA and average S/I joint contact center in the RCT patients, but this relationship was not statistically significant \((r=-0.24, \ p=0.15, \ \text{Fig. } 2)\). When the data from CTL subjects and RCT patients were pooled to investigate this relationship over the greatest possible range of CSA, a significant negative correlation was detected \((r=-0.23, \ p=0.04)\).

**Discussion:** The finding that the CSA was significantly greater in the shoulders of rotator cuff patients than in healthy volunteers agrees with the previously published findings from Moor and colleagues [1]. However, contrary to our hypothesis, an increase in CSA was associated with a humerus located more inferiorly on the glenoid during shoulder abduction. This in-vivo relationship directly contradicts the relationship that had been previously suggested based on cadaveric studies and computer simulations [2, 3], which reasoned that a larger CSA would result in superior migration of the humerus relative to the glenoid. There are several plausible explanations for this unexpected finding. First, it’s possible that normal physiological contact between the greater tuberosity of the humerus and the soft tissues overlying the lateral aspect of the acromion forces the humerus to translate inferiorly on the glenoid during shoulder abduction. This phenomenon may occur at lower abduction angles in shoulders where the high(er) CSA is due to increased lateral extension of the acromion, thus causing the average S/I joint contact center to be located more inferiorly on the glenoid. Another plausible explanation is that the CSA may have only a modest influence on in-vivo glenohumeral joint motion. Indeed, the data suggest that CSA explains only about 5-10% of the variability in the average S/I contact center. It is entirely possible that the scapula’s resting posture, neuromuscular factors, scapulohumeral rhythm, or other morphological parameters not accounted for by the CSA have a more significant influence on in-vivo glenohumeral joint motion. Future efforts will continue to examine the complex relationship between bony morphology and in-vivo joint motion.

**Significance:** The critical shoulder angle is significantly different between patients with rotator cuff tears and volunteers with healthy shoulders, and this particular morphological parameter has a significant, albeit modest, influence on in-vivo glenohumeral joint motion. Surprisingly, the relationship between the critical shoulder angle and in-vivo glenohumeral joint motion is contrary to what would be expected based on previously reported studies.
Fig. 1: The critical shoulder angle (CSA) is a morphological parameter that accounts for both glenoid inclination and lateral extension of the acromion.
Fig. 2: Contrary to our hypothesis, a larger critical shoulder angle (CSA) was associated with a more inferior location of the humerus on the glenoid during abduction for both healthy volunteers ($R=0.30, p=0.038$) and rotator cuff tear patients ($R=0.24, p=0.15$).