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The effect of critical shoulder angle on functional compensation in the setting of cuff tear arthropathy

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Introduction: Critical shoulder angle (CSA) has been shown to influence rates of rotator cuff tears and glenohumeral arthritis with a larger CSA associated with rotator cuff tears and a smaller CSA associated with glenohumeral arthritis. There has been no study to determine whether such radiographic measurement influences the function of patients with demonstrated cuff tear arthropathy (CTA). The purpose of this study was to examine whether smaller CSAs were associated with greater range of motion (ROM) in patients diagnosed with CTA.
Materials and methods: Ninety-three patients with a diagnosis of CTA with adequate anteroposterior shoulder radiographs were included in the study. Patient demographics were recorded. The presence of a rotator cuff tear was confirmed via advanced imaging or when applicable via the operative report. Patients' ROM was evaluated through the physician's office note. Shoulder radiographs were used to measure CSA, glenoid inclination, acromial index (AI), and acromiohumeral interval. Patient ROM was measured and grouped into 2 different tiered cohorts: cohort 1 had 4 subgroups of forward elevation (FE) (ie, $\leq 45°$, 45°-90°, 91°-135°, and 136°-180°) and cohort 2 had 2 subgroups of FE (ie, $\leq 90°$ and $>90°$). We then analyzed FE between these groups in the context of their radiographic measurements.
Results: The average patient age was 73.8 ± 8.0 years. There was no significant difference in acromiohumeral interval. AI was found to be significantly different between patients presenting with $\leq 90°$ in FE compared with those $>90°$ ($P = .02$). Average CSA was significantly lower in patients with FE greater than 90° at 33.7° ± 3.9° compared with patients with FE less than 90° at 37.1° ± 6.3° ($P = .002$). There was also a significant difference with regard to CSAs, with those patients with FE $\leq 45°$ having a mean CSA of 38.2° ± 8.3° compared with those patients with FE $\geq 135°$ having a mean CSA of 33.3° ± 4.3° ($P = .02$).
Conclusion: Patients diagnosed with CTA can significantly vary in their shoulder function and ability to forward elevate. Lower CSA was found to be associated with higher FE in patients with CTA preoperatively. In addition, patients with a smaller AI were also found to have better overhead function. Analyzing CSA on plain radiographs may help manage functional expectations in patients with CTA.

Cuff tear arthropathy (CTA), first described in 1983 by Neer et al,[19] is a chronic condition where massive rotator cuff tears (RCTs) lead to instability and disuse in the glenohumeral joint, resulting in humeral head atrophy and proximal migration. An intact rotator cuff produces a net inferior and compressive force to counteract the superior directed force of the deltoid. With a massive RCT, there is an uncoupled and unopposed superiorly directed deltoid force, leading to proximal humeral migration, degeneration of the acromion and coracoid, and reduced motion.[4,7] This pathology leads to the clinical symptoms often seen in patients with CTA including but not limited to restricted forward elevation (FE) and abduction of the arm.[5,7,22] Among these patients with decreased function, there is a subset who cannot elevate their arms actively beyond 90° despite intact passive range of motion (ROM). These patients are defined as having pseudoparalysis.[5] However, there remain patients who are diagnosed with CTA who are able to compensate and maintain the functional use of their arms.

The critical shoulder angle (CSA) is a radiologic measurement of the scapula that examines the inclination of the glenoid as well as the lateral extension of the acromion.[17] Patients with a larger CSA are often found to have either an increased superior tilt of the glenoid, a larger lateral extension of the acromion, or a combination

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of both. This anatomical geometry of the scapula can result in an increased stress on the rotator cuff. Nyffeler et al[21] originally suggested that the more lateral acromion alters the resultant force vector of the middle deltoid muscle fibers that, in turn, can lead to a greater stress on the supraspinatus as it attempts to counteract the proximally driven vector. In addition, a more lateral acromion decreases the compressive force component created by the deltoid, which, when combined with a superiorly inclined glenoid face, allows the humeral head to be more easily driven upward. Moor et al[17] took this theory and examined the true anteroposterior (AP) shoulder radiographs of patients with either osteoarthritis or RCTs. The authors found that patients with larger CSAs had a higher likelihood of RCTs, whereas those with smaller CSAs had a higher likelihood of osteoarthritis of the glenohumeral joint.[3,17]

Considering that there exists a population of patients who have CTA but are still able to function with good FE, we decided to extrapolate this idea of CSA as it applies to the function of patients with CTA. We hypothesize that this radiographic parameter could impact the function of the cuff-deficient glenohumeral joint with smaller CSAs affording patients' greater active FE. We also hypothesize that a smaller acromial index (AI) and a larger acromiohumeral interval may correlate with greater active FE.

Material and methods

This study was a single-center, retrospective cohort study of patients diagnosed with CTA between January 2019 and September 2019. Patients were included if they had the diagnosis of CTA, were older than 18 years, and had preoperative AP shoulder radiographs. Patients were excluded if they had a fracture, a history of previous ipsilateral shoulder surgery, acute traumatic tears, or inadequate plain radiographic imaging. CTA was diagnosed by fellowship-trained surgeons based on clinical findings and shoulder radiograph findings, as described by Neer et al.[19] However, if further confirmation was necessary, CTA was confirmed through either advanced diagnostic imaging or, in the case of those patients who went on to surgery, via reporting of a rotator cuff tendon tear in the operative report for reverse total shoulder arthroplasty (RSA). All patients included in the study were either treated nonoperatively or with RSA. No other surgical treatments were performed on patients included in the study.

Radiographs were standardized to AP radiographs of the affected shoulder taken within 1 year from the index office visit. Measurements were performed by 2 reviewers overseen by 1 fellowship-trained surgeon. Radiographic measurements included CSA, AI, glenoid inclination (GI), and acromiohumeral interval (AHI). Radiographs were accessed through the Sectra PACS system (Sectra Medical, Shelton, CT, USA). CSA was measured, as defined by Moor et al,[17] with a line from the inferior pole of the glenoid to the superior pole and a line from the inferior pole of the glenoid to the lateral edge of the acromion (Fig. 1). AI was measured as the ratio of the distance between the glenoid pole and the lateral edge of the acromion to the distance between the glenoid pole and the lateral edge of the humerus (Fig. 2). AHI was measured as the distance between the undersurface of the acromion and the greater tuberosity of the humerus (Fig. 3). GI was measured as defined by Maurer et al,[15] where the beta angle was subtracted from 90°. The beta angle is defined as the angle formed between the floor of the supraspinatus fossa and the glenoid pole (Fig. 4). Shoulders were then classified based on the degree of CTA, as described by Hamada et al.[10]

Preoperative FE, age, gender, and body mass index (BMI) for each patient were obtained from the patient's first office visit electronic medical record. The patient's progression to reverse shoulder arthroplasty was recorded as well when performed.

Forward elevation analysis was undertaken in 2 different ways. First patients were grouped into 4 cohorts (ie, ≤45°, 46°-90°, 91°-135°, and >135°) and 2 cohorts (ie, ≤90° and >90°) based on FE (Table I). Cohorts were chosen to examine the degree of influence CSA had on FE. Analysis was taken under these 2 different ways to note the influence of CSA on CTA as it pertains to function and the various definitions of pseudoparalysis.

Statistical analysis was performed to assess the effect of these radiographic measurements on FE. The data were found not to be normally distributed, and a correlational analysis between FE and CSA was performed using a nonparametric Spearman's test. In addition, analysis was performed by grouping FE values and performing Mann-

Figure 1 Critical shoulder angle (CSA).

Figure 2 Acromial index (AI).

Figure 3 Acromiohumeral interval (AHI).

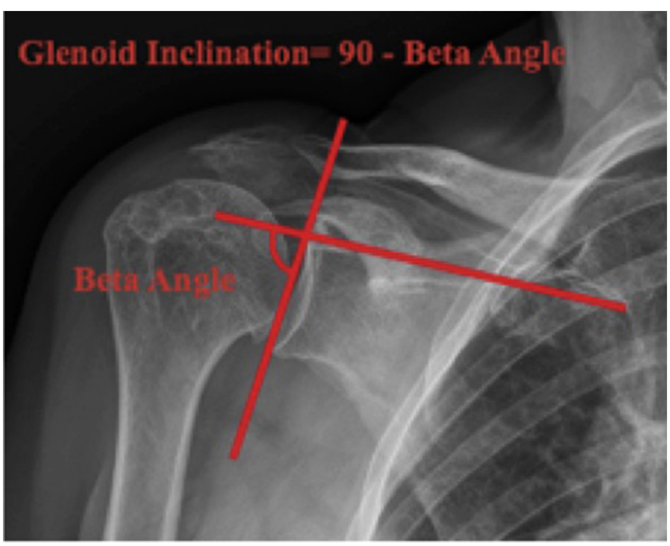

Figure 4 Glenoid inclination.

Whitney *U* and Kruskal-Wallis tests. The Mann-Whitney *U* test was used when FE was grouped into 2 cohorts (ie, ≤90º vs. >90º), and Kruskal-Wallis was performed when FE was grouped into 4 cohorts (ie, ≤45º, 45º-90º, 91º-135º, and 136º-180º). The follow-up Mann-Whitney *U* test was performed for post hoc pairwise analysis. All statistical analyses were performed with Statistical Package for the Social Sciences (SPSS) Statistics software 26 (IBM Corp., Armonk, NY, USA).

Results

Demographics

After applying inclusion and exclusion criteria following IRB approval, 93 patients were included in this study for analysis—62 females and 31 males with an average age and BMI of 73.8 ± 8.0 years and 29.3 ± 6.4 kg/m^2, respectively (Table I). All 93 patients were diagnosed and treated for CTA with either nonoperative treatment (ie, corticosteroid injections, nonsteroidal anti-inflammatory drugs, therapy) or RSA. Of the 93 patients, 30 underwent RSA (32.3%) as their treatment choice at the time of evaluation.

Forward elevation

BMI, age, and gender were not significantly different between FE cohorts. Likewise, AHI measurements were not different between any of the cohorts. CSA measurements were significantly different for multiple cohorts ($P = .002$ for <90° vs. >90° groups, $P = .02$ for <45° vs. >135°, $P = .006$ for 46°-90° vs. >135°) (Table II). The Hamada classification was not found to be significantly different between patients with FE ≤ 90° compared with patients with FE > 90°. No other significance was found between cohorts. In addition, AI was found to be significantly different between patients presenting with ≤90° of FE and patients presenting with >90° of FE (0.8 vs. 0.7; $P = .02$). Of the 30 patients who went on to RSA, 20 patients had FE ≤90° whereas 10 patients had FE >90°.

Correlational analysis shown in Table III was performed with all patients in the study. Patients with smaller CSA were found to have greater FE (Spearman's rho = −0.259, $P = .012$). A more inferiorly tilted glenoid was correlated with a smaller CSA (Spearman's rho = 0.323, $P = .002$). In addition, a larger AI was correlated with higher CSA (Spearman's rho = 0.854, $P < .001$). No other parameters measured were found to be correlated with FE.

Discussion

This is the first study to examine CSA as it relates to patients with CTA as a measure of their function. All patients in this study had a demonstrated RCT with a mean CSA of 35.5° ± 5.6°. We hypothesized that the function of these patients could be partially influenced by some of the same radiographic parameters that put patients at risk for RCT vs. osteoarthritis. In the setting of CTA, the deltoid is no longer opposed by the deficient rotator cuff forces. As such, the fulcrum created by the compressive and downward force of the rotator cuff is lost. Despite this, some patients with CTA are still able to demonstrate reasonable shoulder function with FE above 90°. Part of this functional compensation could be attributed to a more inferior tilted glenoid that creates more resistance to the superior vector of the deltoid and allows the humeral head to pivot. In addition, a more medial extension of the acromion decreases the vertical shear of the deltoid fibers proposed by Nyffeler et al,[21] which aids in elevation of the arm. This notion was confirmed by our data as we demonstrated that patients diagnosed with CTA with greater than 90° of FE had a smaller average CSA when compared with the average CSA of patients with less than 90° of FE. The average CSA of patients with FE less than 45° was found to be greater than the average CSA of patients with FE greater than 135° (38.2° vs. 33.3°; $P = .017$). The average CSA of patients with FE between 46° and 90° was also found to be greater than the average CSA of patients with FE greater than 135° (37.1° vs. 33.3°; $P = .006$). In addition, we found a negative correlation between CSA and FE, suggesting that smaller CSA leads to less deficit in FE. Previous studies have demonstrated good interobserver reliability of CSA with Moor et al[17] reporting a bias of 0° with limits of agreement of −2° to +2°. Bjarnison et al[2] demonstrated a systematic difference between observers of 1.5° for CSA in patients with RCT and 0.7° for CSA in patients with osteoarthritis . Furthermore, the Hamada classification did not appear to affect FE in patients with CTA as the Hamada classification between FE ≤ 90° vs. FE > 90° was not significantly different ($P = .182$). This study demonstrates an association between a lower CSA and preservation of ROM in patients

Table I
Demographic data for the entire cohort

Number of patients	93
No. with confirmed RCT, n (%)	49 (51)
Age (yr)	73.8 ± 8.0
Sex	62F, 31M
BMI (kg/m^2)	29.3 ± 6.4
Mean CSA	35.5° ± 5.6°
No. proceeded to RSA, n (%)	30 (32.3)
Forward elevation ≤90° before RSA	20
Forward elevation >90° before RSA	10

RCT, rotator cuff tear; *BMI*, body mass index; *CSA*, critical shoulder angle; *RSA*, reverse total shoulder arthroplasty.

Table III
Correlational analysis for measurements and range of motion

Variables	Full cohort	
	Correlation	*P* value
CSA degrees		
Affected shoulder FE	−0.259	.012
Glenoid inclination	0.323	.002
Acromial index	0.854	<.001
Affected shoulder FE		
Acromial index	−0.146	.160
AHI	−0.039	.712

CSA, critical shoulder angle; *FE*, forward elevation; *AHI*, acromiohumeral interval

with known CTA and shows the significance of CSA in patients who already have known cuff tears.

Cuff tear arthropathy describes a form of glenohumeral arthritis secondary to long-term rotator cuff deficiency. Patients with CTA have varying degrees of function in respect to FE, losses ranging from 15° to 60°, and external rotation, losses ranging from 10° to 35°.[8,23,29] CSA is a radiologic measurement, which takes into account the GI and the AI, associated with degenerative joint disease and RCTs.[17] Previous studies have demonstrated the association between CSA and development of rotator cuff disease.[1,6,9,13,18] Nyffeler et al[21] proposed that with larger acromial extension, the middle fibers of the deltoid are almost straight, allowing more humeral elevation. With a smaller acromion, the ascension force decreases whereas the compressive force on the humeral head increases.[21] Terrier et al[26] demonstrated a similar finding in a 3D finite-element study where a larger acromion increased superior translation of the humeral head during active FE . Moor et al[17] applied this idea and further demonstrated an association between smaller CSAs with glenohumeral arthritis and larger CSAs with RCTs. The authors noted that those with CSA > 35° were more likely to demonstrate RCTs, whereas those with CSA < 30° were more likely to demonstrate osteoarthritis.[13] Heuberer et al[12] found patients with osteoarthritis had lower CSAs (27.3° ± 3.5°) compared with patients with RCTs (36.3° ± 2.7°; $P < .001$), corroborating the results of Moor et al. In addition, in a subset of patients with CTA, the mean CSA was 35.2° ± 2.8°, similar to the results of this study.[12] Watanabe et al[27] noted that patients with RCTs had a larger CSA compared with patients without RCTs ($P < .001$). Li et al[14] similarly found that CSAs > 35° were associated with RCTs, due to the increased superior shear forces, whereas CSAs < 30° were associated with glenohumeral osteoarthritis, due to increased compressive forces across the glenohumeral joint. The value of this study is that it is the first to demonstrate the difference in the cuff-deficient shoulder function as it relates to radiographic parameters. One of the complications commonly described after RSA is loss of external rotation and internal rotation.[11,25,28] Given the known loss of external and internal rotation after RSA, these findings may be useful in identifying patients who may be more successfully treated with reconstruction options such as superior capsular reconstruction, partial rotator cuff repair, or tendon transfer before considering reverse shoulder arthroplasty. Mihata et al[16] reported an average active external rotation improvement of 14° after superior capsular reconstruction. These evolving techniques help to preserve patient anatomy that is one major drawback of reverse arthroplasty. Further studies are required to determine the biomechanical basis and the clinical utility of these findings with the hopes of determining better indications for these techniques. In advanced CTA disease, reverse shoulder arthroplasty is often the best surgical option, but we hope that this study will encourage further investigation into alternative treatment options.

This study was limited by the retrospective, case-control study design. One could argue that patients identified earlier in the disease course may have higher FE compared with those identified later. However, the Hamada classifications did not significantly differ between FE cohorts, suggesting that in our study, radiographic progression of CTA did not play a significant role in determining FE. In addition, a larger sample size may have allowed for identification of other radiographic measurements with the impact on ROM. Another limitation involves the subjective nature of measuring ROM. Forward elevation data were collected from reports by multiple shoulder and elbow surgeons, potentially introducing some error into the data. However, this is how we communicate as surgeons in real everyday practice so it is realistic. Finally, some patients who were diagnosed with CTA and went on to reverse shoulder replacement because of significant pain or poor function did not require advanced imaging. Even though they were demonstrated to have an RCT on examination

Table II
Demographic data and measurements based on forward elevation

	≤45°	46°-90°	91°-135°	>135°	*P* value	≤90°	>90°	*P* value
	N = 16	N = 36	N = 12	N = 29		N = 52	N = 41	
Age (yr)	75.2 ± 6.1	72.9 ± 8.1	71.8 ± 5.9	74.5 ± 9.2	.479	73.6 ± 7.6	73.7 ± 8.4	.956
Sex								
Male	7 (24.1%)	10 (34.5%)	2 (6.9%)	10 (34.5%)	.441	17 (58.6%)	12 (41.4%)	.450
Female	9 (14.1%)	26 (40.6%)	10 (15.6%)	19 (29.7%)		35 (54.7%)	29 (45.3%)	
BMI (kg/m^2)	28.0 ± 6.6	30.7 ± 7.2	28.8 ± 5.3	28.6 ± 6.2	.460	29.9 ± 7.0	28.7 ± 5.9	.391
CSA degrees (°)	38.2 ± 8.3	37.1 ± 5.0	34.5 ± 2.8	33.3 ± 4.3	.015*	37.1 ± 6.3	33.7 ± 3.9	.002
Acromial index	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	.780	0.8 ± 0.1	0.7 ± 0.1	.023
Hamada classification								
Hamada ≤3						34 (65.4%)	32 (78%)	.182
Hamada >3						18 (34.6%)	9 (22%)	
AHI (mm)	5.7 ± 3.6	4.7 ± 2.8	5.9 ± 1.9	4.7 ± 2.6	.111	5.3 ± 3.3	5.2 ± 2.7	.966

BMI, body mass index; *CSA*, critical shoulder angle; *AHI*, acromiohumeral interval.
* ≤45° vs. >135°, $P = .017$; 46°-90° vs. >135°, $P = .006$.

and at the time of surgery, there was no quantitative assessment of the size of their cuff tear or qualitative assessment of their cuff muscle atrophy. However, the AHI between all cohorts was not significantly different. Previous studies have shown a correlation between AHI and RCT size.[20,24] Lastly, as CTA progresses, it is possible that increased wear patterns on the glenoid can eventually lead to changes in the measured CSA. This is much more of concern with a more advanced wear pattern demonstrated in a Sirveaux E2/E3 glenoid. Although we did not use this classification scheme, the majority of patients in our study were Hamada Grade 3 or less that are less worn patterns seen with CTA. In addition, there was no noted impact of Hamada Grade on FE. Further studies using other classification schemes are certainly warranted. We realize that the function of the cuff-deficient shoulder is multifactorial and that the size of the tear of the rotator cuff and amount of atrophy can also influence patient ROM.

Conclusion

Patients diagnosed with CTA can significantly vary in their shoulder function and ability to forward elevate. Although multifactorial, this study demonstrates that a smaller CSA in the setting of a RCT is significantly correlated with better FE function compared with those patients with larger CSAs. In addition, patients with a smaller AI were also found to have better overhead function. Such radiographic parameters may serve as a valuable assessment in determining which treatment options to consider in the cuff-deficient patient.

Disclaimer

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