The critical shoulder angle (CSA) in glenohumeral osteoarthritis: Does observer experience affect measurement reliability on plain radiographs? [☆]

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ABSTRACT

Background: The critical shoulder angle (CSA) has been associated with full-thickness rotator cuff tears both in the presence and absence of glenohumeral arthritis. It is unclear whether the CSA can be reliably measured from plain radiographs of concentric glenohumeral osteoarthritis amongst examiners at differing levels of training.

Methods: We retrospectively reviewed the radiographs of consecutive patients who underwent shoulder arthroplasty for glenohumeral osteoarthritis. The CSA was measured on a standardized AP scapular view at baseline and then 4 weeks later by fellowship-trained orthopaedic surgeons, a shoulder fellow and a senior orthopaedic resident. Grade of arthritis was categorized using the Samilson and Prieto method. The inter- and intra-observer reliability was then determined for all examiners, as well as for increasing severity of radiographic arthritis. The relationship between the CSA and grade of arthritis was assessed.

Results: There were 166 included patients comprised of 104 females (63%) and 62 males (37%) with a mean age of 65.9 ± 10.4 years. The inter- and intra-observer reliability for measuring the CSA amongst all examiners was found to be excellent, with an intra-class coefficient (ICC) of > 0.9 ($p < 0.0001$). The ICC remained excellent even amongst radiographs with more advanced arthritis. Furthermore, there was a weak, inverse relationship between the grade of arthritis and the CSA ($r = -0.377$, $p < 0.005$).

Conclusion: The CSA can reliably be measured by examiners at varying levels of orthopaedic training, even with more advanced radiographic glenohumeral osteoarthritis. Level of evidence: Level III (Prognostic).

1. Introduction

Glenohumeral osteoarthritis (OA) is one of the most common etiologies of shoulder pain, with increasing prevalence in patients > 60 years.¹ Similarly, rotator cuff tears (RCTs) also represent one of the most common musculoskeletal disorders in the United States. It has been estimated that as many as 17 million people in the US are affected by RCTs, and these lead to over 4.5 million office visits and 40,000 surgeries per year.² Although full-thickness RCTs are uncommonly associated with OA,³ recent studies have estimated the prevalence at 8–9%.^{4,5} The association between a full-thickness RCT and glenoid loosening following an anatomic total shoulder arthroplasty has previously been demonstrated.⁶

As originally described by Moor et al., the critical shoulder angle (CSA) is a radiographic measurement that concurrently assesses the inclination of the glenoid and the lateral extension of the acromion.⁷ The authors demonstrated that a CSA $< 30^\circ$ was associated with

glenohumeral OA and values $> 35^\circ$ were associated with full-thickness RCTs. The association between degenerative shoulder pathology and the CSA has subsequently been validated.⁸ Biomechanical studies have postulated that a higher CSA results in an increased ratio of joint shear forces to joint compression forces, thereby increasing supraspinatus loads.⁹ The CSA may be a useful, simple diagnostic tool for determining the presence of a full-thickness RCT in the setting of glenohumeral OA. Recently, Mantell and colleagues found higher CSA measurements in patients with OA and concomitant RCTs compared to patients with glenohumeral OA alone.¹⁰ Most recently, Hawi and colleagues demonstrated that the CSA was poorly correlated with the grade of humeral-sided arthritis, but that glenoid inclination had good statistical correlation.¹¹ These measurements were made by shoulder-trained orthopaedic surgeons.

The CSA may be a useful screening tool to identify concomitant RCTs patients undergoing total shoulder arthroplasty. It is unclear from the current literature whether the CSA can reliably be measured by

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Fig. 1. Radiographs demonstrating (a) grade 1, (b) grade 2 and (c) grade 3 glenohumeral osteoarthritis as defined utilizing the Samilson and Prieto classification. Measurement of the CSA is shown in each case.

surgeons at differing levels of training, even with standardized AP scapular radiographs. Furthermore, it has not been universally accepted that this measurement can be reliably made as the severity of glenohumeral arthritis worsened, particularly as the bony landmarks become more difficult to elucidate. We therefore sought to determine: 1) the inter- and intra-observer reliability of the CSA measurement amongst examiners of different levels of orthopaedic training; 2) the inter- and intra-observer reliability of the CSA measurement for all examiners with increasing severity of radiographic arthritis; and 3) the relationship between the CSA and the grade of arthritis as categorized using a commonly utilized radiographic assessment of glenohumeral arthritis. Our hypothesis was that the inter-observer reliability of the CSA will improve from a resident-, fellow-, and attending-level measurements. Further, we hypothesized that the greater degree of coronal plane arthritis will be negatively correlated overall with inter-observer reliability as well as intra-observer reliability.

1.1. Patients and methods

We retrospectively reviewed the medical records of all patients who underwent primary shoulder arthroplasty by two fellowship-trained shoulder surgeons at our institution from January 2006 through January 2018. Institutional Review Board approval was obtained for this study (BLINDED). Inclusion criteria included any patient who underwent shoulder arthroplasty for osteoarthritis and had a baseline AP scapular radiograph available in our picture archiving and communication system (PACS). Exclusion criteria included patients who had sustained prior fracture of the glenoid or acromion with or without surgical intervention, had undergone prior shoulder arthroplasty, and those with inadequate pre-operative radiographs. Furthermore, radiographs demonstrating proximal humeral migration (acromiohumeral distance < 8 mm) or who had radiographs and/or history consistent with inflammatory arthritis were excluded. Demographic data was collected from the electronic medical record including age, gender, height, weight, BMI, presence of hypertension or diabetes, and procedure side. The intact nature of the posterior-superior rotator cuff was subsequently verified at the time of the shoulder arthroplasty for all of the cases included.

All radiographs were evaluated using our institution's PACS imaging software. All radiographs were pre-screened in a blinded fashion by 2 examiners (BLINDED) for inclusion to determine if they met the study criteria (ie, the glenohumeral joint at the center of the image, affected arm in neutral position, and < 5 mm overlap between the anterior and posterior glenoid). The 2 examiners also graded the severity of humeral-sided arthritis using the classification of Samilson and Prieto.¹² Any discrepancy in the grade was resolved through consensus. The critical shoulder angle (CSA) was measured as described by Moor et al. as the angle between a line connecting the superior and inferior aspects of the glenoid and another line connecting the inferior border of the glenoid to the most lateral aspect of the acromion.⁷

All included shoulder radiographs were then distributed for CSA

measurement in a blinded and randomized fashion. The examiners included 2 fellowship-trained shoulder surgeons each with > 10 years clinical experience, a clinical shoulder fellow, and a 4th year orthopaedic surgery resident at our institution. Each examiner reviewed the published technique for measuring the CSA prior to initiating the study. After the initial measurements were recorded, a second measurement was undertaken 4 weeks later. The lists were randomized prior to the performance of the second set of measurements. All CSA measurements were compiled in a de-identified excel sheet for data analysis.

1.2. Statistical analysis

Statistical analysis was performed using SPSS Version 24 (SPSS Inc, Chicago, IL, USA). Continuous variables were given as a mean with standard deviation. Comparison between continuous variables was performed using the t-test and one-way ANOVA. A Pearson's correlation coefficient (r) was calculated to describe the relationship between grade of arthritis and CSA. Inter- and intra-observer reliability was presented as an Intraclass Correlation Coefficient (ICC). The following conventional benchmark values were used: a value between 0 and 0.19 describes a poor agreement; 0.20 to 0.39, a fair agreement; 0.40 to 0.59, a moderate agreement; 0.60 to 0.79, a good agreement; and 0.80 to 1.00, an excellent agreement. The significance level for all tests was set at $p < 0.05$.

2. Results

We initially identified 208 consecutive patients with centered glenohumeral osteoarthritis, of which 166 (80%) met the inclusion criteria. There were 30 cases excluded as a result of inadequate radiographs, 6 cases for likely inflammatory etiology and 6 cases because of a history of prior ipsilateral shoulder surgery. There were 104 females (63%) and 62 males (37%) with a mean age of 65.9 ± 10.4 years. Using the Samilson and Prieto system, there were 41 (25%) cases classified as grade 1, 34 (20%) as grade 2, and 91 (55%) as grade 3 (Fig. 1). The demographics for patients within each of the grades of arthritis are given in Table 1. The intra-class coefficient (ICC) between readers for the first and second reading amongst all grades of arthritis was found to be excellent. (0.97, 95% CI 0.96–0.98, $p < 0.0001$) The inter- and intra-observer reliability for each grade of arthritis is given in Table 2. Overall, the mean CSA following the initial measurement amongst all examiners was 30.4° . Amongst all reviewers, the mean CSA was $33.6^\circ \pm 5.99^\circ$, $31.7^\circ \pm 6.23^\circ$, and $28.5^\circ \pm 4.77^\circ$ for grades 1, 2 and 3, respectively. ($p < 0.0005$) The CSA was significantly lower in patients with grade 3 arthritis compared with those with grade 1 ($p < 0.0005$) and grade 2 arthritis ($p < 0.026$). However, only a weak overall correlation could be identified between the CSA and worsening grade of arthritis. ($r = -0.377$, $p < 0.0005$) (Table 3) A similar correlation was identified by each of the examiners, regardless of their level of training.

Table 1
General characteristics of patient population.

Demographic	Radiographic Grade of Arthritis			
	Grade 1 (n = 41)	Grade 2 (n = 34)	Grade 3 (n = 91)	p-value
Mean age $\pm$ SD (years)	64.2 $\pm$ 12.9	66.1 $\pm$ 10.6	66.6 $\pm$ 9.0	0.47
Gender				
Male	13	11	38	0.43
Female	28	23	53	
Height $\pm$ SD (m)	1.61 $\pm$ 0.11	1.63 $\pm$ 0.12	1.65 $\pm$ 0.09	0.11
Weight $\pm$ SD (kg)	85.13 $\pm$ 14.76	86.01 $\pm$ 17.32	87.66 $\pm$ 16.53	0.69
BMI $\pm$ SD (kg/m ²)	33.35 $\pm$ 7.15	32.60 $\pm$ 7.78	32.31 $\pm$ 6.52	0.73
Medical co-morbidities				
Hypertension				0.25
Present	30	20	67	
Absent	11	14	24	
Diabetes				0.62
Present	17	13	30	
Absent	24	21	61	

SD: Standard deviation; BMI: Body mass index.

Table 2
Inter- and intra-observer reliability by grade of arthritis.

Grade 1 Arthritis		
<i>Intra-observer</i>		
Examiner	ICC (95% CI)	p-value
A	0.98 (0.96–0.99)	< 0.0001
B	0.94 (0.89–0.97)	< 0.0001
C	0.96 (0.92–0.98)	< 0.0001
D	0.97 (0.94–0.98)	< 0.0001
Inter-observer, 1st reading	0.97 (0.95–0.98)	< 0.0001
Inter-observer, 2nd reading	0.95 (0.93–0.97)	< 0.0001
Grade 2 Arthritis		
<i>Intra-observer</i>		
Examiner	ICC (95% CI)	p-value
A	0.99 (0.97–0.99)	< 0.0001
B	0.95 (0.91–0.98)	< 0.0001
C	0.95 (0.89–0.97)	< 0.0001
D	0.98 (0.96–0.99)	< 0.0001
Inter-observer, 1st reading	0.97 (0.95–0.98)	< 0.0001
Inter-observer, 2nd reading	0.98 (0.96–0.99)	< 0.0001
Grade 3 Arthritis		
<i>Intra-observer</i>		
Examiner	ICC (95% CI)	p-value
A	0.97 (0.95–0.98)	< 0.0001
B	0.96 (0.94–0.97)	< 0.0001
C	0.97 (0.95–0.98)	< 0.0001
D	0.96 (0.94–0.97)	< 0.0001
Inter-observer, 1st reading	0.97 (0.95–0.98)	< 0.0001
Inter-observer, 2nd reading	0.97 (0.96–0.98)	< 0.0001

Examiner A,B: Fellowship-trained surgeons; Examiner C: Fellow.

Examiner D: Orthopaedic Resident; ICC: Intra-class correlation coefficient.

3. Discussion

The main findings of this study are that there is a high inter- and intra-observer reliability in the measurement of the critical shoulder angle (CSA) amongst patients with centered glenohumeral osteoarthritis, even amongst examiners of lower degrees of orthopaedic

training. We also found a weak inverse relationship between the CSA and worsening severity of radiographic arthritis.

The CSA has gained popularity within recent literature as a potential predictor of full-thickness rotator cuff tears, both in the presence¹⁰ and absence^{7,13} of glenohumeral osteoarthritis. Additionally, the CSA has been associated with glenohumeral arthritis,^{7,11} though this finding has not been universally established.¹⁴ While the mean CSA in control patients is reported between 33° and 34°, higher CSA values have been found in the presence of rotator cuff tears, whereas lower CSA values have been associated with a higher prevalence of arthritis.^{7,8,10,11,13,15} Moor and colleagues reported that a CSA > 35° was associated with rotator cuff tears, while values < 30° were significantly more common in patients with arthritis.⁷ Prior studies have shown that patients with rotator cuff tears have worse clinical outcomes following a total shoulder replacement, partly from eccentric loading of the glenoid component and early loosening.^{5,6} Recently, Watling et al. reported that higher CSA values was associated with a higher incidence of glenoid loosening following anatomic total shoulder replacement.¹⁶ Measuring the CSA with a plain radiograph provides a simple and useful tool to screen for possible rotator cuff pathology in patients with osteoarthritis, and may serve as a means with which to predict the development of glenohumeral arthritis.

Contrary to our hypothesis, we found that the inter- and intra-observer reliability for the CSA, as measured by the ICC, was > 0.9, and remained excellent even amongst worsening radiographic arthritis. This is consistent with prior studies that have shown similarly good inter- and/or intra-observer reliability for CSA measurement in patients with glenohumeral osteoarthritis.^{7,8,11,14,15} Moor and colleagues reported similar findings amongst patients with osteoarthritis, but the examiners were practicing orthopaedic surgeons and only a single reader was used to determine the intra-observer reliability.⁷ In contrast to our study, reliability measurements were based on the entire cohort and not stratified for the grade of arthritis. In a study of 50 patients with osteoarthritis, Hawi et al. demonstrated excellent inter-observer reliability (ICC 0.86), though the measurements were not repeated and a modified Samilson and Prieto classification was used.¹⁴ Additionally, measurements were performed by shoulder-trained orthopaedic

Table 3
Correlation between arthritis grade and mean CSA measurement.

	All Examiners	Examiner A	Examiner B	Examiner C	Examiner D
Pearson correlation coefficient	−0.377	−0.367	−0.394	−0.370	−0.345
p-value	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

surgeons. Blonna et al. reported a similarly high reliability in the CSA measurement amongst patients with concentric arthritis utilizing 2 observers, one of whom was an experienced surgeon and the other a graduate medical student.⁸ While they found an independent association between CSA and concentric arthritis, there is no mention of the precise distribution of the grades of arthritis in their cohort. Finally, Bjarnison and colleagues reported excellent reliability of the CSA amongst experienced reviewers, though the reliability was not stratified by grade of arthritis.¹¹ We stratified our cohort by the degree of arthritis, which affirms that the excellent reliability remains even with advanced arthritis, where bony landmarks may be obscured by degenerative changes. In fact, 75% of our cases had grade 2 or 3 arthritis. Our junior investigators were a shoulder fellow and a fourth year orthopaedic surgery resident, both of whom obtained excellent measurement reliability, similar to the senior authors. These results may be applicable to both an academic practice, but also to general orthopaedic practitioners.

In addition, we also found a significantly lower mean CSA in those patients with more advanced arthritis. Correlation analysis demonstrated a weak, inverse relationship between the CSA and the grade of coronal plane radiographic arthritis. Our findings are most consistent with those of Blonna et al., who also reported a significant inverse relationship (Spearman's rho, -0.36) between the parameters, even following multivariable analysis including patient age.⁸ Others, however, have found non-significant correlation in the relationship between CSA and worsening grade of arthritis.¹⁴ Whether our finding reflects an increased eccentric wear of the glenoid in more advanced stages of osteoarthritis or a short acromion predisposing to arthritic changes due to increased deltoid reactive forces cannot be elucidated from our study design.¹⁷ In other words, the inverse association between the CSA and arthritis may simply be a result of acquired deformity of the glenoid and not a predisposing factor for developing arthritis. Bjarnison and colleagues found that patients with a CSA $< 30^\circ$ were 2.25 times likely to demonstrate arthritis compared to matched controls.¹¹ However, the authors express caution in interpreting this result given the rarity of glenohumeral arthritis, as well as their definition of a clinically relevant OR > 3 used in their study design. In contrast to Blonna et al., we did not find a significant association between age and the grade of concentric arthritis, although we similarly did not find that gender or the presence of hypertension were related to worsening arthritis.⁸ Future research will be needed to assess other patient-related factors that may concomitantly affect the development of glenohumeral arthritis.

There are certainly some limitations to our study. In our radiographic evaluation we elected a limit of 5 mm glenoid rim overlap as a quality marker because of its simplicity and consistency of the results in prior studies. It has been shown that the CSA remains unchanged with up to 20° of scapular rotation,⁷ or with up to 5 mm of overlap between the anterior and posterior glenoid.⁸ However, more recently, a 5° change in perspective was found to effect a 2° change in the CSA in a cadaveric model.¹⁸ Whether this finding can be translated to the clinical setting remains unclear. We graded OA according to the Samilson and Prieto classification,¹² which has been proven to have a high inter- and intra-observer reliability.¹⁹ One limitation of this classification is that it is solely based on the extent of humeral-sided osteophytes. In addition, the Samilson and Prieto classification limits our evaluation to the coronal plane. However, Moor et al. reported no association between the CSA and glenoid morphology using the Walch classification measured on CT scans.⁷ Nevertheless, it is possible that a different classification with the focus on other radiographic findings would have yielded a different result. Our least experienced examiner was a fourth year orthopaedic surgery resident. The reliability of the CSA measurement might have differed with the inclusion of more junior residents or medical students. However, we felt that the use of residents and fellows currently on service would most closely mimic actual clinical scenarios. Strengths of our study include the high number of patients involved, the different degree of expertise of the investigators, the number of

advanced osteoarthritic patients in our cohort, and the fact that reliability analysis was performed for each participant.

4. Conclusion

The CSA can be reliably measured on plain radiographs of patients with glenohumeral osteoarthritis by examiners with different levels of experience, and the severity of glenohumeral arthritis does not negatively affect reliability of the measurements. There is an inverse relationship between the CSA and worsening grades of osteoarthritis, although this has not been consistently reported. Given the discordance in the literature regarding the association between the CSA and glenohumeral osteoarthritis, further studies are needed to assess other potential radiographic or patient-related confounders to this relationship.

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Sriram Sankaranarayanan: Conceptualization, Methodology, Investigation. **Benjamin R. Saks:** Conceptualization, Methodology, Investigation. **Ari J. Holtzman:** Conceptualization, Methodology, Investigation. **Eloy Tabeayo:** Writing - review & editing, Project administration. **Frances Cuomo:** Conceptualization, Methodology, Investigation. **Konrad I. Gruson:** Investigation, Writing - original draft.

Declaration of competing interest

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