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Original article

Implication of bone morphology in degenerative rotator cuff lesions: A prospective comparative study between greater tuberosity angle and critical shoulder angle[☆]

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INFO ARTICLE

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ABSTRACT

Background. – Degenerative rotator cuff tear is a frequent and multifactorial pathology. The role of bone morphology of the greater tuberosity and lateral acromion has been validated, and can be measured with two plain radiographic markers on true anteroposterior views: the greater tuberosity angle (GTA) and the critical shoulder angle (CSA). However, the interdependence of both markers remains unknown, as well as their relationship with the level of professional and sports activities involving the shoulder. The aim of this prospective comparative study was to describe the correlation between the GTA and CSA in patients with degenerative rotator cuff tears.
Hypothesis. – GTA and CSA are independent factors from one another and from demographic factors, such as age, dominance, sports, or professional activities.
Patient and methods. – All patients presenting to a shoulder specialized clinic were assigned to two groups. The first consisted of patients with a symptomatic degenerative rotator cuff tear visible on MRI and the control group consisted of patients with any other shoulder complaints and no history or visible imaging of any rotator cuff lesion.
Results. – There were 51 shoulders in 49 patients in the rotator cuff tear group (RCT) and 53 shoulders in 50 patients in the control group. Patient demographics were similar in both groups. Mean GTA was 72.1° ± 3.7 (71.0–73.1) in the RCT group and 64.0° ± 3.3 (63.1–64.9) in the control group ($p < 0.001$). Mean CSA was 36.7° ± 3.7 (35.7–37.8) in the RCT group, and 32.1° ± 3.7 (31.1–33.1) in the control group ($p < 0.001$). A summation of GTA and CSA values over 103° increased the odds of having a rotator cuff tear by 97-fold ($p < 0.001$). There was no correlation between GTA and CSA, nor between GTA or CSA and age, sex, tear size, or dominance. Patients with different levels of professional and sports activities did not have significantly different GTA or CSA values.
Conclusion. – GTA and CSA are independent radiologic markers that can reliably predict the presence of a degenerative rotator cuff tear. A sum of both values over 103° increases the odds of having a rotator cuff tear by 97-fold. These markers are not correlated with patient demographic or environmental factors, suggesting that the variability of the native acromion and greater tuberosity morphology may be individual risk factors for rotator cuff tear.
Level of evidence. – II; diagnostic study.

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1. Introduction

Rotator cuff degeneration and tearing is a complex multifactorial process involving intrinsic, extrinsic, biologic, mechanical and biomechanical factors. It is a frequent source of medical consultation and thus has a substantial socioeconomic burden [1,2], with extended sick leaves in the working population [3]. With a current trend towards healthcare expenditure restrictions [4] and recurring global financial crisis [5], a pragmatic and efficient practice of medicine is of paramount importance. Therefore, emphasis should be placed on the use of a meticulous clinical examination and radiographic workup as a frontline tool for screening patients consulting with a shoulder complaint before turning to expensive and sometimes avoidable imaging modalities such as MRI or CT scan.

Several radiographic markers have been associated with rotator cuff tears, most centered around acromion morphology [6–8]. The Critical Shoulder Angle (CSA) was described in 2013 by Moor et al. [8] and measures the lateral extension of the acromion relative to the glenoid plane in the frontal plane (Fig. 1A). The implication of the proximal humerus bony morphology in rotator cuff tear has also recently gained interest [9–12]. The greater tuberosity angle (GTA) was described in 2018 by Cunningham et al. [9] and measures the superolateral extension of the greater tuberosity relative to the humeral head in the frontal plane (Fig. 1B). It is the first marker to establish a relationship between the native morphology of the greater tuberosity and symptomatic rotator cuff tear.

However, no study has yet analysed the combined predictive effectiveness of both angles. Although bone morphology is only a piece of an intricate puzzle in the pathogenesis of degenerative rotator cuff tears, the shape of the scapula and the humeral head could compensate for one another. Combined with incorrectly executed radiographs [13] and many potential confounding factors, this double-sided participation could be another reason why some authors did not find a significantly increased CSA in their studied cohort [14]. Also, although there is a known association between physical activity and rotator cuff tear [15], there is no clear evidence whether morphologic characteristics are fixed or depend on environmental factors such as professional and sports activities involving the shoulder.

The aim of this prospective comparative study was thus to perform a correlation analysis between GTA and CSA in patients with and without degenerative rotator cuff tears. We hypothesized that both markers were two independent factors, and that they were not influenced by demographic factors such as age, dominance, sports, or professional activities.

2. Patients and methods

2.1. Patients

After receiving approval from the ethics committee, we conducted a prospective comparative study including all consecutive patients presenting to a major shoulder clinic between 2017 and 2019. Patients were screened by a shoulder specialist surgeon (GC, blinded for review purposes) for study eligibility and were later included in two groups. The first group consisted of patients with a symptomatic degenerative rotator cuff lesion involving the supraspinatus visible on MRI. Patients with isolated subscapularis tears, traumatic tears or any previous history of surgery or trauma to the same shoulder, were excluded. The second group consisted of patients with any other shoulder condition and no actual or past history of rotator cuff related tear or pain based on clinical examination and MRI or ultrasound imagery. In both groups, patients with post-traumatic or congenital deformity, rotator cuff tear arthropathy, significant osteophytes of the greater tuberosity or coraco-acromial ligament enthesopathy, were excluded.

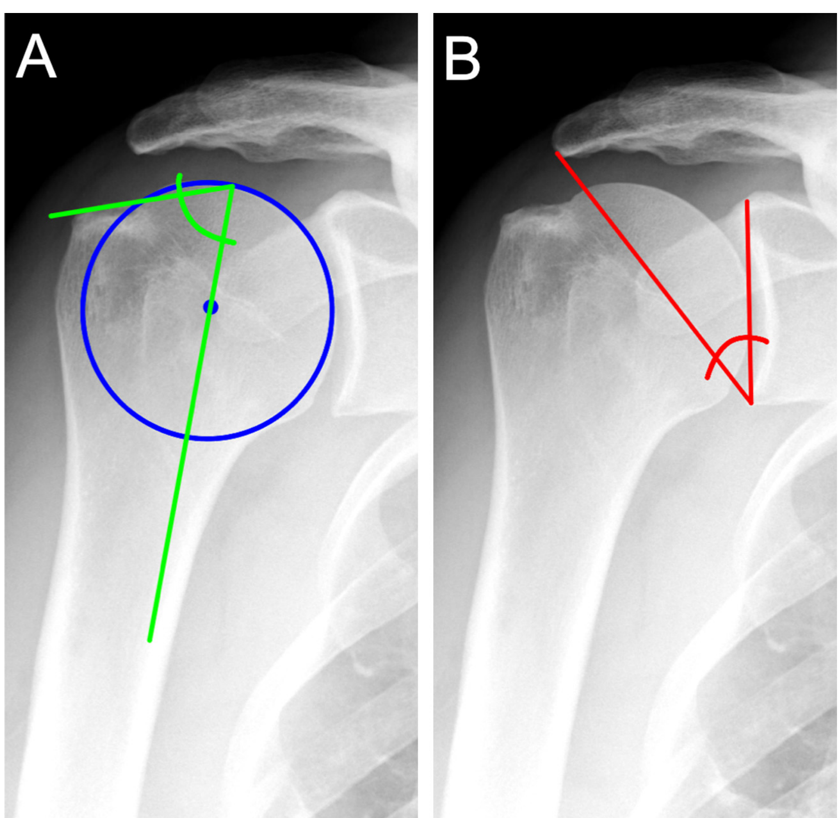

Fig. 1. Standard anteroposterior radiograph illustrating the greater tuberosity angle (GTA) (A) and the critical shoulder angle (CSA) (B).

Table 1
Patient data.

Variable	RCT group (n = 49)	Control group (n = 50)	p
Age (years)	51.1 ± 8.1 (48.8–53.5)	48.1 ± 9.8 (45.3–50.9)	0.099
Sex, n			0.36
Male	21	26	
Female	28	24	
Affected side, n			0.64
Right	26	30	
Left	21	17	
Both	2	3	
Dominance, n			0.57
Right	48	48	
Left	1	2	
Dominant side affected, %	59	70	0.26
Professional activity			0.35
None	7	2	
Administration	29	34	
Moderate/heavy labour	13	14	
Sport activity			0.28
None	15	9	
Light to moderate	23	31	
Heavy/competitive	11	10	

RCT: rotator cuff tear.

Table 2
Results.

	RCT group (n = 51)	Control group (n = 53)	p
GTA (°)	72.1 ± 3.7 (71.0–73.1)	64.0 ± 3.3 (63.1–64.9)	< 0.001
CSA (°)	36.7 ± 3.7 (35.7–37.8)	32.1 ± 3.7 (31.1–33.1)	< 0.001

RCT: rotator cuff tear; GTA: greater tuberosity angle; CSA: critical shoulder angle.

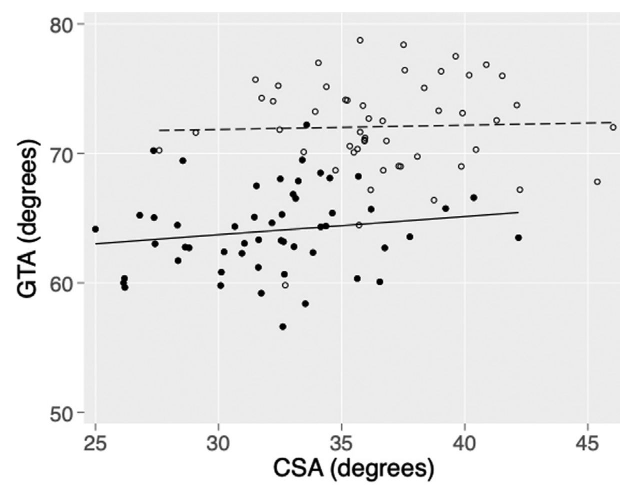

Fig. 2. Scatter diagram showing no significant correlation between greater tuberosity angle (GTA) and critical shoulder angle (CSA) in either patient (empty circles, r = 0.158 in, p = 0.82) or control group (full circles, r = 0.257, p = 0.26).

3. Methods

All included patients had a radiograph taken of their shoulder, which is part of the routine primary assessment. This exam was carried out by the same technician team who were specifically instructed to acquire a true anteroposterior view of the shoulder with the arm in neutral rotation. Correct positioning was validated using previously described protocols [8,9,16]. Any improperly performed radiograph was repeated. Patients' demographics including age, gender, hand dominance, affected side, sports involving the shoulder (such as tennis, handball, weight-lifting) and professional activity were recorded. Sport activities involving the shoulder were classified between 0 and 2 (none, light to moderate, competitive), and professional activities between 0 and 2 (none, light, moderate/heavy manual labor). Rotator cuff tear size was classified as described in a previous study (partial-thickness tear, and small, medium, large or massive for full-thickness tear) [9].

3.1. Angle measurements

Radiologic analysis of the GTA and CSA was carried out using Osirix software (Pixmeo, Geneva) by two independent group-blinded observers (GC and CC, blinded for review purpose). The methodology to measure the angles was meticulously replicated from their original description [8,9]. Inter- and intra-observer has already been shown to be high for both markers [8,9], so only one measurement was carried out by both observers.

3.2. Statistical analysis

Stata 16 (StataCorp, College Station, TX, USA) was used for all statistical analysis. Patient numbers of 50 per group gave us at least 90% power to detect a 10-fold change in the odds ratio for GTA, CSA and the effect of professional or sporting activities (using three levels) based on the variability of our previous results [9]. Baseline patient characteristics were compared using Chi^2 tests of proportions (ratios, percentages) or Student t-test for age. The patient and control correlations between GTA, CSA and age were determined using the Pearson method, and between GTA or CSA and tear category by the Spearman procedure. Interobserver reliability testing and concordance were assessed using the methods of Bland–Altman [17] and Lin [18]. Linear regression was used to determine the significance of dependent variables on GTA and CSA between groups. Ordinal logistic regression was used to determine the increased odds of having a tear above different angle cut-off values. Statistical significance was set at $p < 0.05$.

4. Results

4.1. Patient data

Patients' demographics is summarized in Table 1. There were 51 shoulders in 49 subjects in the RCT group and 53 shoulders in 50 patients in the control group. There was no significant difference between both groups in terms of age, sex ratio, affected side, dominant side, professional or sports activities. In the rotator cuff tear group, there were 37 partial tears, 16 full-thickness tears (7 small, 5 medium, 3 large, and 1 massive tears). Patients with a professional activity had a significantly increased odds of having a rotator cuff tear than those who did not work, whether it be light (p = 0.001), or moderate to heavy labor (p = 0.011). Professional or sports activities had no significant effect on the odds of having a tear (p = 0.33 and 0.13, respectively).

4.2. GTA and CSA results

GTA and CSA values were both significantly higher in the RCT group (Table 2). Mean GTA was 72.1° ± 3.7 (71.0–73.1) in the RCT group compared to 64.0° ± 3.3 (63.1–64.9) in the control group (p < 0.001). Mean CSA was 36.7° ± 3.7 (35.7–37.8) in the RCT group compared to 32.1° ± 3.7 (31.1–33.1) in the control group (p < 0.001).

4.3. GTA and CSA correlation analysis

There was no correlation between GTA and CSA in either group (Fig. 2). Pearson's correlation coefficient was 0.158 for the RCT group (p = 0.82) and 0.257 for the control group (p = 0.26). GTA

Table 3
Sum of GTA and CSA cut-off values (ordinal logistic regression; all $p < 0.001$).

GTA + CSA cut-off value	Increased odds of having a tear if GTA + CSA > cut-off value	False positive	False negative
(°)	(95% CI)	*n* (%)	*n* (%)
101	42 (13–140)	11 (21)	4 (8)
102	60 (17–209)	8 (15)	4 (8)
103	97 (26–364)	5 (9)	4 (8)
104	46 (15–140)	4 (8)	7 (14)
105	47 (15–147)	3 (6)	8 (16)
106	29 (10–83)	1 (2)	13 (25)

GTA: greater tuberosity angle; CSA: critical shoulder angle.

and CSA did not correlate with age, sex, tear size or dominance (all $p > 0.1$). Professional and sports activities did not significantly correlate with GTA or CSA. Patients with a sum of GTA and CSA values over 103° had a 97-fold increase in odds of having a rotator cuff tear ($p < 0.001$) compared to patients with values below 103° (Table 3). Below a cut-off of 103°, there was a higher percentage of false positives; above a cut-off of 103° there was a higher percentage of false negatives. Interobserver concordance was high for both angles, with $r = 0.922$ ($p < 0.001$) for GTA, and $r = 0.916$ ($p < 0.001$) for CSA (Fig. 3).

5. Discussion

This study shows that patients with a degenerative rotator cuff tear have a significantly higher GTA and CSA, confirming previous findings. Moor et al. initially described a mean CSA of 38° (range: 29.5 to 43.5°) in patients with rotator cuff tears [8]. Although controversies exist, mainly in regards to its underlying mechanism and therapeutic implication [19–26] many subsequent studies have shown that a high CSA value is predictive for a rotator cuff tear [24,27–29]. In a large retrospective series of 1000 cases, Heuberer et al. recently showed that CSA was a better predictor for a rotator cuff lesion than acromion index (AI) or the lateral acromion angle [30]. Cunningham et al. initially reported a mean GTA of 72° (range: 67.9 to 97.2°) [9] in patients with rotator cuff tears. Three subsequent retrospective studies by Seo et al., Yoo et al., and Gatot et al. further reported a mean GTA between 71.5 and 73.2° in patients with rotator cuff tears [10,11,31]. The studies by Seo et al., Yoo et al. further looked at tear pattern characteristics and found no association with tendon delamination but a significant correlation between CSA and articular-sided partial tears and between GTA and bursal-sided partial tears (both $p < 0.001$) [10,11]. In this study, there was no association between GTA and tear size. However, we did not look at delamination pattern or partial tear morphology because both parameters remain an arthroscopic finding and most of the patients were not operated.

Looking at the relationship between GTA and CSA, we found no correlation between the two markers suggesting they are independent variables. This could explain why some patients with a low CSA but a high GTA may still present with a rotator cuff tear and vice versa (Fig. 4). Moreover, combining both markers increased predictive effectiveness, with a sum of GTA and CSA over 103° increasing the probability of having a tear by 97-fold.

Finally, there was no significant association between GTA or CSA and any demographic factors, nor the level of professional or sport activities involving the shoulder. These important findings suggest that scapula and humeral bone morphology are fixed parameters, independent from environmental factors. It is, however, mandatory to distinguish the native bone morphology from spurs, osteophytes, or enthesopathies, which are adaptive changes and were strictly excluded from the study.

Controversies remain about the utility of such radiological markers and have been the subject of recent editorial commentaries [32–35]. Concern has been raised about positional variability during radiograph acquisition leading to measurement error. There are, however, several ways to minimize imprecisions in omometry, starting with a meticulous and standardized image acquisition technique, and by verifying adequate positioning on the images using validated markers [13,16,36]. Also, these markers are mainly useful predictive tools. They may be useful for screening patients in the clinical setting but their implication in surgical decision making and long-term outcome still remains to be researched. The underlying mechanism and the therapeutic implications of these findings remain to be fully understood. For instance, Billaud et al. showed that anterior acromioplasty could decrease CSA [26]. There is also conflicting evidence that correcting CSA or GTA significantly improves outcome or re-tear rate [19–25,31]. It is however important to note that most studies showing no difference in re-tear rate have a short follow-up period (2–3 years), some report suboptimal correction of CSA [21], others use incomplete outcome measurement tools, with clinical scores only and no imagery to formally exclude recurrence [31,37]. Long-term follow-up studies with adequate methodology are therefore lacking. In summary, the strength of radiological markers such as GTA and CSA for now, mostly resides in their predictive value.

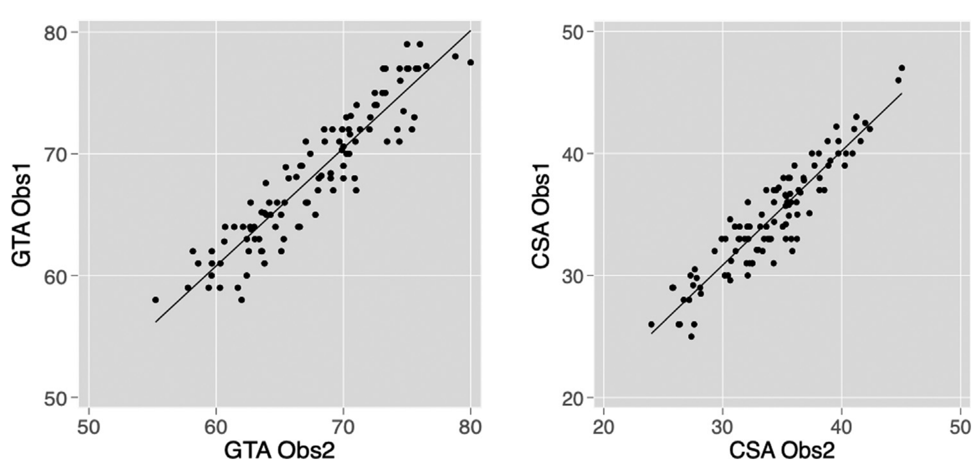

Fig. 3. Scatter diagram showing similarly high interobserver reliability for greater tuberosity angle (GTA, $r = 0.922$, $p < 0.001$), and critical shoulder angle (CSA, $r = 0.916$, $p < 0.001$).

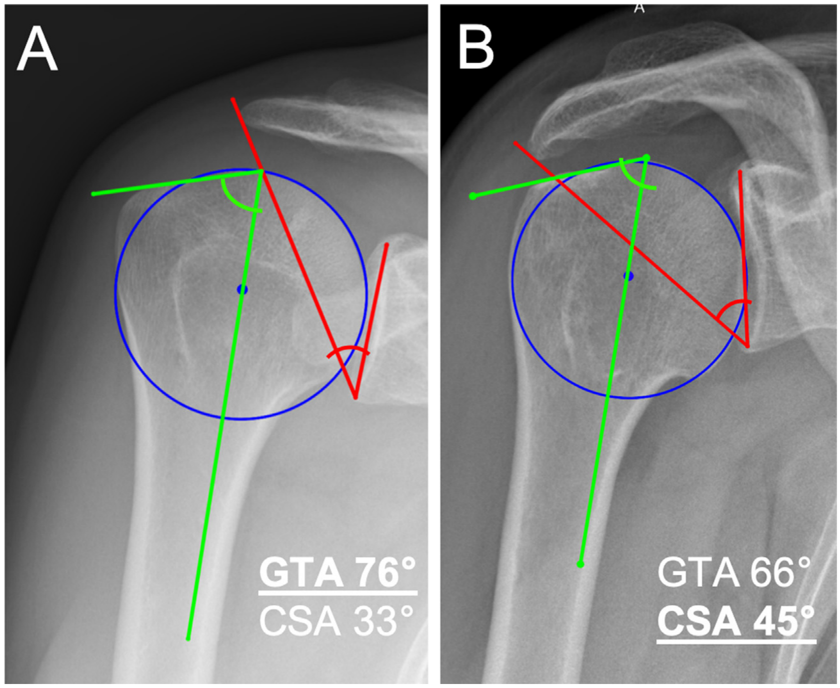

Fig. 4. Radiographs of 2 patients with a degenerative rotator cuff tear. A. High greater tuberosity angle (GTA) and a low critical shoulder angle (CSA). B. High CSA and a low GTA.

The main strengths of this study are that it is highly powered and that it is prospective in nature. However, it remains observational and cannot fully explain the cause of this association, which remains an openly debated question. GTA and CSA are, moreover, two-dimensional markers that most probably result of a complex combination of multiplanar projections and biomechanical factors. We also did not take bilateral x-rays to compare intra-individual variations of GTA and CSA. This would have been useful to further study the influence of hand dominance, although we did not find any significant association with this parameter in transversal analyses ($p = 0.14$ for GTA, and 0.20 for CSA). Finally, we have examined sport intensity according to different groups, and cannot report on individual sports, which would have needed many more subjects.

6. Conclusion

GTA and CSA are independent radiologic markers that can reliably predict the presence of a degenerative rotator cuff tear. A sum of both values over 103° increases the odds of having a rotator cuff tear by 97-fold. These markers are not correlated with patient demographic or environmental factors, suggesting that the variability of the native acromion and greater tuberosity morphology may be individual risk factors for rotator cuff tear.

Disclosure of interest

The authors declare that they have no competing interest.

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Author contribution

G. Cunningham: project leader, investigator, study design, manuscript writing.

C. Cocor: co-investigator, measurements.

M. Smith: statistics.

B. Cass and A. Young: study design, manuscript editing and proofreading.

B. Moor: manuscript writing.

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