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Original article

Critical shoulder angle and greater tuberosity angle according to the partial thickness rotator cuff tear patterns

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ABSTRACT

Background: Current studies suggest that radiographic markers such as the critical shoulder angle (CSA) and the greater tuberosity angle (GTA) are associated with rotator cuff tears (RCTs). However, because the analysis of CSAs and GTAs according to the partial thickness rotator cuff tear patterns is limited, the purpose of the present study was to evaluate the relationship of CSAs and GTAs with partial thickness rotator cuff tear (PTRCT) patterns.
Method: This retrospective study included 1,069 patients from 2013 to 2017. The subjects were divided into 4 groups: Group A, control group; Group B, articular-sided PTRCTs; Group C, bursal-sided PTRCTs; and Group D, full thickness rotator cuff tears (FTRCTs). RCTs were diagnosed with magnetic resonance imaging and the CSA and GTA were measured on simple radiographs. Multivariable analyses were used to clarify the potential risks for these pathologies.
Results: The mean CSAs of articular-sided PTRCTs ($34.2^\circ \pm 4.7^\circ$) and FTRCTs ($34.7^\circ \pm 4.4^\circ$) were significantly larger than those of the control group ($32.3^\circ \pm 4.3^\circ$) and the bursal-sided PTRCTs ($31.5^\circ \pm 4.6^\circ$), ($P < 0.001$). Multivariable analysis also showed that larger CSAs had a significantly increased risk of both articular-sided PTRCTs and FTRCTs, with odds ratios of 1.12 and 1.17 per degree, respectively. The mean GTAs of bursal-sided PTRCTs ($73.2^\circ \pm 4.8^\circ$) and FTRCTs ($72.3^\circ \pm 5.4^\circ$) were significantly larger than that of the control group ($70.5^\circ \pm 5.1^\circ$) ($P < 0.001$), although the mean GTA of articular-sided PTRCTs ($71.5^\circ \pm 6.9^\circ$) did not show a significant difference when compared with the other groups. Multivariable analysis also showed that larger GTAs had a significantly increased risk of both bursal-sided PTRCTs and FTRCTs, with odds ratios of 1.13 and 1.07 per degree, respectively.
Conclusion: A large critical shoulder angle was associated more with articular-sided PTRCTs than bursal-sided PTRCTs. A large greater tuberosity angle was associated more with bursal-sided PTRCTs than with articular-sided PTRCTs. Both critical shoulder angle and greater tuberosity angle were positively associated with the occurrence of full thickness rotator cuff tears.
Level of evidence: : IV, Retrospective study.

1. Introduction

Degenerative rotator cuff tears are common disorders of the shoulder, although the etiology of rotator cuff tears (RCTs) still has not been determined. Mechanisms of rotator cuff tendinopathy have been described classically as intrinsic, extrinsic, or a complex of both [1]. Among the potential disease risk factors, chronic rotator cuff tendon overload was proposed as a major factor [2]. Many studies have reported on the difference of tensile stress between the articular side and the bursal side of the supraspinatus tendon with the maximal stress concentration having been observed on the articular side of the supraspinatus tendon, which might have caused partial thickness tears and delamination [3–5]. Even when all three types of partial tears (articular-side, bursal-side and intratendinous) existed, high stress tensile concentrations were also observed at the articular side, which might be associated with tear progression [5]. Recently, the association between anatomical morphologies and rotator cuff tears was studied. In 2013, Moor et al. first introduced critical shoulder angle (CSA) as a reliable tool for quantifying the relationship of acromion and glenoid shapes with rotator cuff tears and osteoarthritis of the shoulder. [6] In 2014, during a biomechanical study, Gerber et al. indicated that as the CSA of the scapula increases so does the tensile load on the supraspinatus tendon required to stabilize the humeral head in the glenoid [7].

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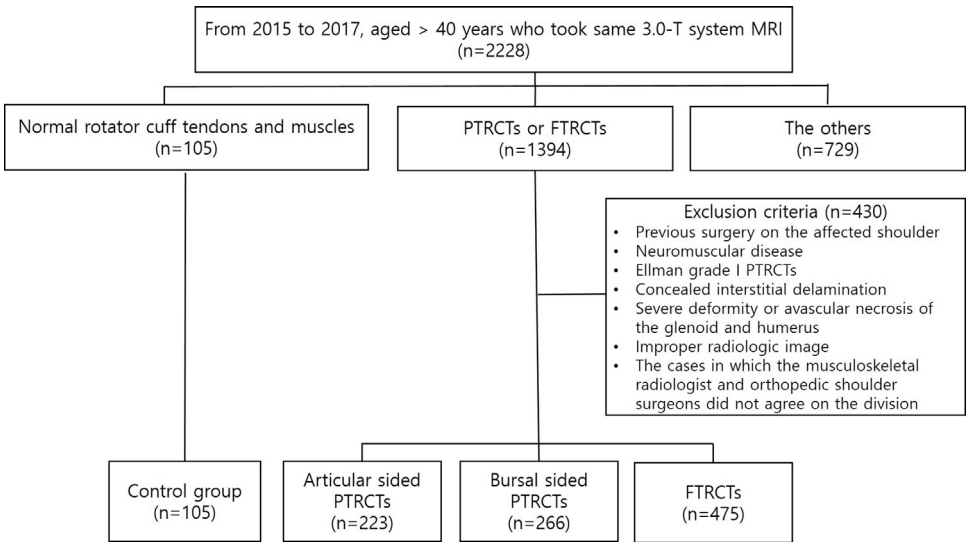

Fig. 1. Study flow diagram. MRI: magnetic resonance image; PTRCTs: partial thickness rotator cuff tears; FTRCTs: full thickness rotator cuff tear.

In 2018, the greater tuberosity angle (GTA) was first introduced as a new predictor for rotator cuff tears. The angle is created by a line parallel to the humeral diaphysis passing through the humeral head center-of-rotation and a line connecting the upper border of the humeral head to the most superolateral edge of the greater tuberosity. The author described the exact underlying cause of a high GTA, yet the association with RCT remains to be elucidated. Hence, in patients with a large GTA, subacromial impingement might exist from an extrinsic point of view. With an intrinsic point of view, higher tensile loads might be required because of more divergence from the deltoid [8].

Several studies reported on the relationship of RCTs with a large CSA and GTA, [6,8–12] and Cunningham et al. [8] demonstrated that a large CSA is associated with FTRCTs, not with PTRCTs. However, since the analysis according to PTRCTs patterns (articular sided vs. bursal sided) is limited, the purpose of the present study was to evaluate the relationship among CSA, GTA, and PTRCTs patterns.

2. Material and methods

After obtaining ethical approval (DKUH 2018-12-023) for this study, we retrospectively identified and included 1,069 patients from 2015 to 2017 aged >40 years who had shoulder pain. Nine hundred sixty four patients were diagnosed with PTRCTs and FTRCTs by a musculoskeletal radiologist using the same type of magnetic resonance imaging (MRI) system so that they could be evaluated under the same conditions. One hundred five patients who had normal rotator cuff tendons and muscles according to their MRIs were enrolled as the control group. Subjects who had previous surgery on the affected shoulder, neuromuscular disease, Ellman grade I PTRCTs, concealed interstitial delamination, severe deformity or avascular necrosis of the glenoid and humerus, and improper radiologic image were excluded from this study (Fig. 1).

Using the subjects' MRIs, PTRCTs were divided into articular-sided and bursal-sided groups by a musculoskeletal radiologist. The subjects were divided into four groups: Group A, control group; Group B, articular-sided PTRCTs; Group C, bursal-sided PTRCTs; and Group D, FTRCTs. Patient information was obtained from their medical records and included age, sex, dominant hand, height, weight, body mass index, and smoking history.

The groups were divided by musculoskeletal radiologist, and MRI findings were repeatedly interpreted by a consensus readout of another blinded observer (shoulder surgeon; K.H.). The musculoskeletal radiologist was considered the main assessor, the evaluation by the orthopaedic shoulder shrgeon (K.H.) was used to assess the interobserver correlation. The cases in which agreement on the division was not achieved by the musculoskeletal radiologist and shoulder surgeon were excluded, although the interobserver correlation had an almost perfect agreement ($k = 0.89$).

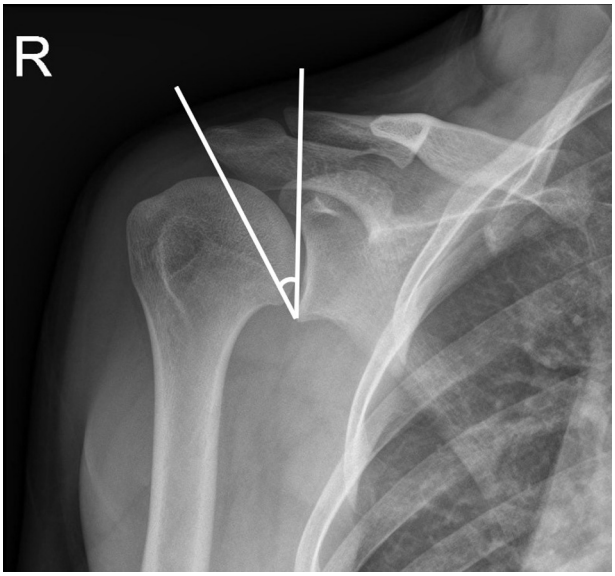

Fig. 2. The angles between a line connecting the superior and inferior osseous margins of the glenoid cavity and a line connecting the inferior osseous margins of the glenoid cavity and the inferolateral border of the acromion were measured as the critical shoulder angle.

2.1. Measurement of the CSA and the GTA

The CSA was measured from true anterior-posterior radiographs using the method described by Moor et al. [6]. The angle was determined using a line from the inferior border of the glenoid to the lateral aspect of the acromion and a line drawn from the superior to inferior border of the glenoid (Fig. 2).

The GTA was also measured from radiographs, using the method described by Cunningham et al. [8]. The angle was formed using a line parallel to the humeral diaphysis passing through the humeral

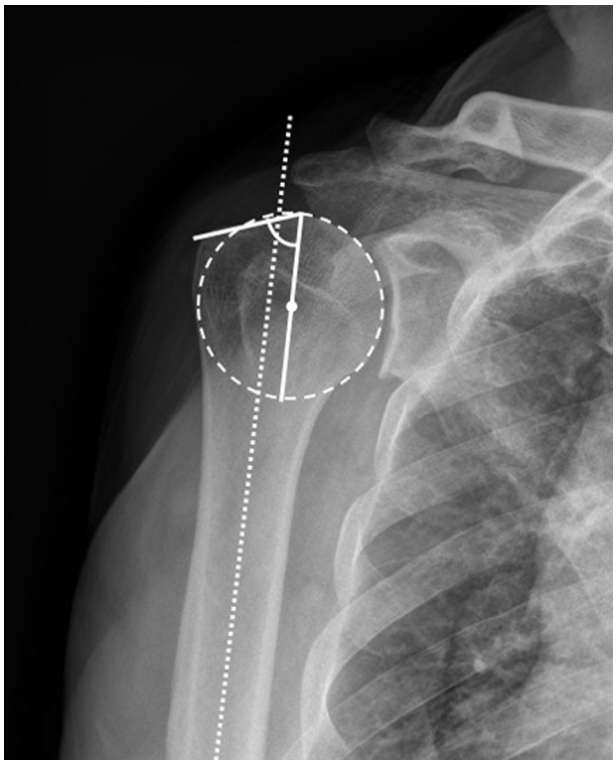

Fig. 3. The angles between a line that parallel line to the diaphyseal axis passing though the humeral head center of rotation and a line connecting the upper border of the humeral head to the most superolateral edge of the greater tuberosity were measured as the greater tuberosity angle.

head center-of-rotation and a line connecting the upper border of the humeral head to the most superolateral edge of the greater tuberosity (GT) (Fig. 3).

For this study, two shoulder surgeons (K.H. and S.M.K.) independently measured both the CSA and the GTA at 2 different times, 2 months apart. The observers were blinded to each other's measurements and the group identities. Both intra-observer and inter-observer reliabilities for CSA and GTA measurements were almost in perfect agreement (Table 1).

2.2. Statistical methods

Differences in the CSAs and GTAs among the four groups were examined using a one-way analysis of variance (ANOVA) test and post hoc analysis with Tukey's range test. The weighted kappa coefficient was used to estimate the inter-observer reliability and the intra-observer reliability for CSA and GTA measurements. Reliability was classified according to the kappa coefficients: "slight agreement," 0.00–0.20; "fair agreement," 0.21–0.40; "moderate agreement," 0.41–0.60; "substantial agreement," 0.61–0.80; and "almost perfect agreement," 0.81–1.00. All statistical analyses were performed using SPSS version 21.0 (SPSS Inc., Chicago, IL, USA). Multivariable-adjusted analyses for the occurrence of both PTRCTs and FTRCT was performed using logistic regression analysis. Statistical significance was set at $P < 0.05$.

3. Results

Of the 1,069 patients included in this study, there were 105 patients with no RCTs (Group A), 223 patients with articular-sided PTRCTs (Group B), 266 patients with bursal-sided PTRCTs (Group C), and 475 patients with FTRCTs (Group D). All of the basic demographic data showed no statistically significant differences among groups, except in age and terms of smoking (Table 2, Fig. 4).

The mean CSA was 32.3°±4.3° in Group A, 34.2°±4.7° in Group B, 31.5°±4.6° in Group C, and 34.7° ± 4.4° in Group D. The CSA of both Group B and D was significantly larger than that of Group C and A (Group A vs. B: $P = 0.001$, Group A vs. D, Group B vs. C and Group C vs. D: $P < 0.001$) (Table 3, Fig. 5).

The mean GTA was 70.5°±5.1° in Group A, 71.5°±6.9° in Group B, 73.2°±4.8° in Group C, and 72.3°±5.4° in Group D. The GTA of Group C and D was significantly larger than that of Group A (Group A vs. C: $P = 0.009$, and Group A vs. D: $P = 0.031$). However, the mean GTA of Group B showed no significant differences when compared with the other groups (Table 4, Fig. 6).

Multivariable analysis showed that larger CSAs significantly increased the risk of articular-sided PTRCTs and FTRCTs, with odds ratios of 1.12 per degree for group B and 1.17 for Group D. Moreover, larger GTAs significantly increased the risk of bursal-sided PTRCTs and FTRCTs, with odds ratios of 1.13 for Group C and 1.07 for Group D. Age and sex were risk factors for RCTs and FTRCTs, respectively (Table 5).

4. Discussion

This is the first study to show that the associations between radiologic parameters (CSA and GTA) and PTRCTs were different depending on the extrinsic or intrinsic nature of the tear. A large CSA was associated more with articular-sided PTRCTs than with bursal-sided PTRCTs. A large GTA was associated more with bursal-sided PTRCTs than with articular-sided PTRCTs. Both CSAs and GTAs were positively associated with the occurrence of FTRCTs.

There are many mechanisms associated with rotator cuff tears [1,13–15]. Tensile stress overload on the rotator cuff tendons is one of the RCT mechanisms [1,3,13,16]. Infinite element analyses, a high tensile stress concentration was on the articular side of the supraspinatus tendon [3,4,16]. Sano et al., also showed high tensile stress concentrations on the articular side when all 3 types of partial tears were present [5]. Histologically, Nakajima et al., reported that the articular-side layer was a tendon, ligament, and joint capsule complex, whereas the bursal side layer was composed of tendon bundles. They concluded that the articular-side layer is more vulnerable to tensile loads than the bursal side [13]. Tensile stresses on the rotator cuff tendon would be more associated with the articular side than the bursal side.

In addition, Moor et al., first proposed that the CSA combines two potential risk factors for degenerative RCTs (inclination of the glenoid and lateral extension of the acromion) [6,17]. Many clinical studies support this radiographic marker [11,18,19]. Biomechanical studies verified that high CSAs are associated with a tensile stress overload in the rotator cuff tendon, which might result in RCTs [7,17]. Regarding tensile stress tendon overload, we hypothesized that larger CSAs are associated with the articular-sided PTRCTs and the FTRCTs which propagated from articular-sided PTRCTs. The mean CSA of bursal-sided PTRCTs (38.83° ± 4.18°) reported by Pandey et al. was not significantly higher than that of the control group (37.28 ± 4.89), although the mean CSA of FTRCTs (41.01 ± 3.1) was significantly higher than the control group [19]. However, they did not analyze the CSAs by segregating them into articular- and bursal-sided PTRCTs. In the present study and as we hypothesized, patients with articular-sided PTRCTs and FTRCTs had larger CSAs than those with bursal-sided PTRCTs and no RCTs. In addition, the current multivariable analysis demonstrated that large CSAs had an independent risk of FTRCTs and articular-sided PTRCTs, with odds ratios of 1.17 and 1.12 per degree, respectively.

Compared to previous studies, the CSAs of the groups in our study were different. Moor et al., noted that 84% of patients with a

Table 1
Reliability of radiologic measurements.

Measurement position	ICC(KH vs. KH)	ICC(SMK vs. SMK)	ICC(KH vs. SMK)
Critical shoulder angle	0.94	0.93	0.92
Greater tuberosity angle	0.93	0.92	0.91

ICC: Intraclass correlation coefficient; KH: KH and SMK vs. SMK: intraobserver variation test; KH vs. SMK: interobserver variation test.

Table 2
Demographic data.

	Group A($n=105$)	Group B($n=223$)	Group C($n=266$)	Group D($n=475$)	*P*-value
Age (Mean ± SD)	49.4 ± 9.2	58.9 ± 10.1	58.3 ± 9.6	56.1 ± 8.0	< 0.001
Sex (Male/Female)	77/28	127/96	181/85	290/185	0.133
Right arm/Left arm	61/44	121/102	168/98	304/171	0.387
Weight (kg, Mean ± SD)	68.6 ± 12.2	64.6 ± 12.5	65.5 ± 10.6	66.4 ± 10.7	0.359
Height (cm, Mean ± SD)	166.5 ± 9.5	161.7 ± 9.2	163.9 ± 8.3	163.1 ± 8.5	0.202
Body mass index (Mean ± SD)	24.6 ± 3.3	24.6 ± 3.2	24.4 ± 3.2	25.1 ± 2.9	0.247
Smoking/Non-smoking	40/65	192/31	194/72	352/123	0.028

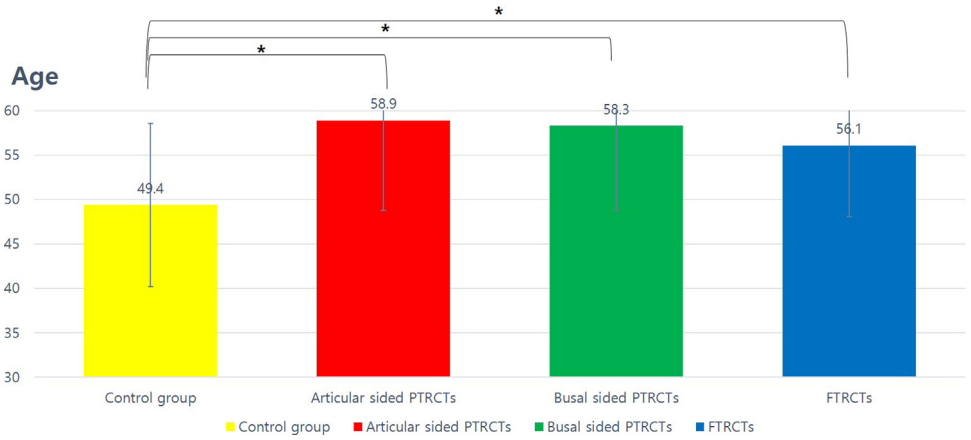

Fig. 4. Comparison of the patients' age. Statistically significant differences are indicated by brackets and an asterisk.

Table 3
Critical shoulder angle and greater tuberosity angle according to the rotator cuff tear patterns.

	Group A($n=105$)	Group B($n=223$)	Group C($n=266$)	Group D($n=475$)	*P*-value
Critical shoulder angle (Mean ± SD)	32.3 ± 4.3	34.2 ± 4.7	31.5 ± 4.6	34.7 ± 4.4	< 0.001
Greater tuberosity angle (Mean ± SD)	70.5 ± 5.1	71.5 ± 6.9	73.2 ± 4.8	72.3 ± 5.4	0.003

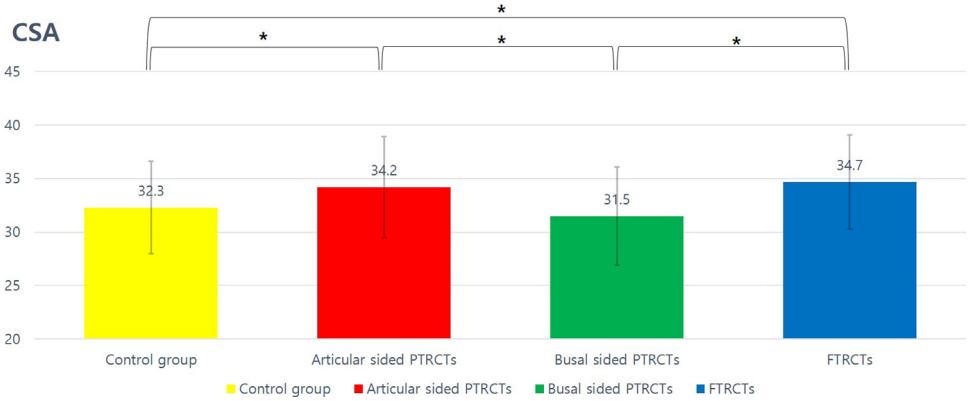

Fig. 5. Comparison of the critical shoulder angle between groups. Statistically significant differences are indicated by brackets and an asterisk.

Table 4
Multiple comparison of critical shoulder angle and greater tuberosity angle according to the rotator cuff tear patterns.

Comparison between the groups	*P*-value ofCritical shoulder angle	*P*-value ofGreater tuberosity angle
Group A vs. B	0.001	0.026
Group A vs. C	0.519	0.009
Group A vs. D	< 0.001	0.031
Group B vs. C	< 0.001	0.065
Group B vs. D	0.379	0.206
Group C vs. D	< 0.001	0.557

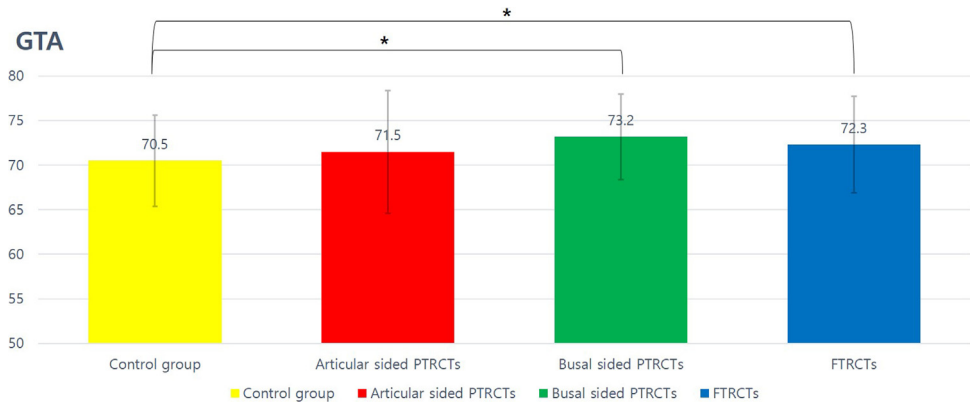

Fig. 6. Comparison of the greater tuberosity angle between groups. Statistically significant differences are indicated by brackets and an asterisk.

Table 5
Odd ratios of critical shoulder angle and greater tuberosity angle according to the rotator cuff tear patterns.

Factor	Odd ratios (95% CI)					
	Group B	*P*-value	Group C	*P*-value	Group D	*P*-value
Critical shoulder angle	1.12 (1.06–1.19)	< 0.001	0.98 (0.92–1.04)	0.521	1.17 (1.09–1.25)	< 0.001
Greater tuberosity angle	1.00 (0.96–1.05)	0.854.	1.13 (1.04–1.22)	0.004	1.07 (1.02–1.12)	0.006
Age, per ten years	1.97 (1.50–2.58)	< 0.001	1.98 (1.42–2.76)	< 0.001	2.02 (1.56–2.61)	< 0.001
Sex, male to female	0.92 (1.02–3.73)	0.860	0.69 (0.89–4.21)	0.115	3.70 (0.96–3.01)	0.001
Right arm to left arm	0.97 (0.53–1.78)	0.924	1.28 (0.62–2.65)	0.513	0.80 (0.47–1.37)	0.803
Body mass index	0.95 (0.87–1.04)	0.949	0.97 (0.86–1.80)	0.531	1.05 (0.96–1.15)	0.324
Non smoker to smoker	1.12 (0.45–1.72)	0.703	1.60 (0.96–1.85)	0.060	1.02 (0.52–1.72)	0.860

CSA > 35° had rotator cuff tears [5]. Pandey et al., reported the CSA of FTRCTs as 41.01° ± 3.1° with the higher CSA cut-off values as > 39.3° [19]. Cabezas et al. [20] recently compared CSAs between North American and East Asian populations and discovered that the CSA was significantly smaller in North Americans than in East Asians (mean 27.7° ± 4.8° vs. 32.8° ± 4.4°, respectively). In 2018, Shinagawa et al., [11] reported that the mean CSA of FTRCTs, PTRCTs, and controls was 34.3° ± 4.2, 32.6° ± 3.2°, and 32.3° ± 4.5° respectively, in 295 East Asians. In this study, the mean CSAs of each group (FTRCTs: 34.7° ± 4.4°, articular-sided PTRCTs: 34.2° ± 4.7°, bursal-sided PTRCTs: 31.5°±4.6°, and the control group: 32.3° ± 4.3°) are similar to the results of Shinagawa et al. [11].

Cunningham et al., [8] first proposed the GTA as a reliable radiographic marker with more than 70° being highly predictive in detecting RCTs. They reported the mean GTA values were 72.5° ± 2.5° in patients and 65.2° ± 4.1° for controls ($P < 0.01$). In the present study, the mean GTA of the control group was 70.5° ± 5.1°, although the mean GTA of FTRCTs (72.3 ± 5.4) was similar to the result of Cunningham et al. [8]. The authors assumed that East Asians had larger GTAs than Europeans because East Asians had smaller humeral heads than Europeans, although the statistical analysis had not yet been performed.

Cunningham et al., [8] suggested that the underlying cause of the association of a high GTA and RCT was unknown and could be the result of the impingement of the GT against the undersurface of the acromion or the tensile stress from divergent vectors between the supraspinatus muscle and the deltoid. However, the influence of the GTA in RCT is still unclear. Our findings showed that while the mean GTA of the bursal-sided PTRCTs was larger than that of the control group, the mean GTA of the articular-sided PTRCTs did not show a significant difference when compared to the control group. However, there was also no statistically significant difference between bursal-sided PTRCTs and articular-sided PTRCTs. Therefore, an additional biomechanical study similar to the CSA studies is required [7].

Our study has several limitations. Firstly, the control group did not include normal healthy patients with normal MRI findings, although they had shoulder pain. Undetected tears found on MRI can be a cause of selection bias. Secondly, the patients in the control group were younger than those in the rotator cuff tear groups. Age-matching comparison is necessary to prove the difference in the relationship of the CSA and GTA between the control and rotator cuff tear groups because CSA and GTA could be changes with increasing age. Comparison between PTRCTs and FTRCTs was possible because there was no difference in the age of the patients in rotator cuff tear groups Thirdly, despite the excellent inter-observer agreement, measurement errors could exist. To reduce such errors, measurements were independently performed and the results were shared between surgeons. Fourthly, radiographs in this study were routinely taken in a neutral position even though the CSA is dependent on the scapular version, the position, and the viewing perspective, [6,21] and the GTA is dependent on the rotation of the upper arm [8]. Although Cherchi et al. [22] reported high reproducibility of CSA measurement by two observers (intra-observer reproducibility: 96.7% and inter-observer reproducibility: 95.5%), it is difficult to achieve 100% accuracy and that should also be counted as a limitation. Fifthly, the difference between the CSA and the GTA with and without rotator cuff tears was approximately 2–3°, whereas the SD was > 4°. Although statistically significant, these results should be carefully interpreted for determining the clinical application of CSAs and GTAs. Sixthly, our study did not consider the internal impingement even though this is also one of the extrinsic RCT mechanisms [1]. Finally, this study did not investigate other morphologic parameters of the acromion, such as the acromial index and the acromial spur.

5. Conclusion

A large critical shoulder angle was associated more with articular-sided PTRCTs than with bursal-sided PTRCTs. A large

greater tuberosity angle was associated more with bursal-sided PTRCTs than with articular-sided PTRCTs. Critical shoulder angles and greater tuberosity angles were both positively associated with the occurrence of FTRCTs.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contribution

J.B.S designed this study, S.M.K. and K.H. measured radiologic findings, J.S.Y. wrote this article.

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