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The critical shoulder angle: can it be sufficient to reflect the shoulder joint without the humeral head?

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Hypothesis: We hypothesized that a new method considering the humeral head would distinguish rotator cuff tears (RCTs) and osteoarthritis (OA) better than the critical shoulder angle (CSA).
Methods: A total of 1011 patients were tested in this study and divided into 4 groups: those with RCTs (n = 493), those with OA (n = 73), those with anterior instability (n = 361), and those with adhesive capsulitis (n = 84). The CSA and new radiologic parameters including the humeral head were measured in the true anterior-to-posterior view: the Y angle connecting the lower end of the glenoid (LG), the center of the humeral head (CH), and the upper end of the glenoid (UG); the G angle connecting UG, CH, and the lateral tip of the acromion; the YG angle connecting LG, CH, and the lateral tip of the acromion; and the R angle connecting UG, LG, and CH.
Results: The CSA and G angle were the largest in the RCT group (34.2° and 70.4°, respectively; $P < .001$) and the smallest in the OA group (29.8° and 61.7°, respectively; $P < .001$). The Y angle was the largest in the OA group (82.8°, $P < .001$). The R angle in the RCT group (52.9°) was significantly larger than that in the OA group, which was the smallest among the groups (48.0°; $P < .001$). The CSA was correlated with the G and YG angles in the RCT group, whereas the CSA was correlated with the Y, G, and R angles in the OA group ($P < .05$). The CSA showed the highest correlation with the size of RCTs (correlation coefficient = 0.138).
Conclusion: The Y, G, and R angles reflected the lesions of RCTs or OA. The CSA showed good correlations with the new radiologic parameters, and it had the highest correlation coefficient with the size of RCTs.

The institutional review board (IRB) approved an exemption for this study owing to its retrospective design (IRB No. KHUH 2018-01-108, Kyung-Hee University Hospital IRB; 1803-010-16155, Chung-Ang University Hospital IRB).

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Although it is well known that various factors are associated with the occurrence of rotator cuff tears (RCTs) and osteoarthritis (OA), their pathogenesis remains unclear. Numerous studies have reported that the morphology of the acromion is related to the causes of these illnesses, and many studies have tried to classify the morphology of the acromion using radiographs.[1,10] Previous studies classified it using acromial tilt,[12] the lateral acromial angle (LAA),[1] the acromial index (AI),[21] or the critical shoulder angle (CSA).[16]

The CSA has recently drawn much attention as an angle to predict the likelihood of RCTs and OA by quantifying the anatomic shape of the scapula without considering the humeral head.[16,18] The CSA is defined as "the angle between the glenoid surface and a line connecting the inferior rim of the glenoid and the lateral tip of the acromion."[25] Moor et al[16] reported that patients with RCTs had a larger CSA than those with OA. A previous biomechanical study showed that a larger CSA had a higher possibility of causing RCTs because it gave a higher load to the supraspinatus to maintain the stability of the glenohumeral joint during abduction.[25] Viehofer et al[26] conducted a biomechanical experiment and reported that a low CSA was a causal factor of OA because it increased loading to the glenohumeral joint.

Moor et al[16] argued that it would be possible to determine the presence of RCTs and OA by measuring the CSA without considering the degenerative changes of the humeral head. However, it is not known whether the results would be consistent even if the morphologic shape of the glenohumeral joint changes. In the presence of extensive RCTs or considerably advanced OA, the anatomic shapes of the glenoid, acromion, and humeral head may be deformed and the deformation may affect the CSA.[19] Because both RCTs and OA influence the articular surface of the glenoid and humeral head, it is questionable whether the CSA alone can reflect the lesion of a shoulder joint accurately. The objectives of this study were to propose a new radiologic evaluation method considering the humeral head, to analyze the correlation between the method and the CSA, and to examine the verification of the CSA in patients with RCTs or OA. This study hypothesized that the new method considering the humeral head would show the differences between various shoulder diseases better than the CSA.

Materials and methods

We evaluated 6377 patients who underwent shoulder joint surgery at 2 hospitals (Kyung-Hee University Hospital, Seoul, Republic of Korea [n = 4704] or Chung-Ang University Hospital, Seoul, Republic of Korea [n = 1673]) between 2008 and 2015. All procedures were performed by 2 surgeons (Y.G.R. and J.Y.K.) in each hospital. We excluded patients who did not have sufficient radiologic evaluation findings (n = 2749), those with humeral head deformation in whom it was difficult to assess the central point of the humeral head (n = 135), those who underwent shoulder surgery on the same shoulder (n = 685), those with a history of trauma or fracture (n = 1686), those with a tumor (n = 28), and those with an infection history (n = 83). As a result, this study analyzed 1011 patients.

The patients were divided into 4 groups (Table I): 493 patients with chronic full-thickness RCTs, 73 patients with OA, 361 patients with anterior instability, and 84 patients with adhesive capsulitis (AC). The anterior instability group was included in this study to evaluate whether age affected radiographic results. Moreover, the AC group was included to evaluate differences in measurements in patients of similar ages with RCTs and OA. Patients with grade 1 (acromiohumeral distance more than 6 mm) or grade 2 (acromiohumeral distance less than 5 mm without "acetabulization" of the acromion), as determined by the modification of the classification of Hamada et al[10] described by Walch et al[27], were included in the RCT group. No patients showed glenohumeral arthritis. In all of the patients in the RCT group, arthroscopic or open rotator cuff repair had been performed successfully. In both arthroscopic and open rotator cuff repairs, the anterior-to-posterior (AP) dimension and medial retraction of the torn rotator cuff were measured with a probe by 2 surgeons (Y.G.R., J.Y.K.) in each hospital and classified as described by DeOrio and Cofield.[6] Tears were divided into small (<1 cm), medium (1-3 cm), large (3-5 cm), and massive (>5 cm or rupture of >2 tendons) and were observed in 133, 228, 85, and 47 patients, respectively. In the OA group, patients were examined using the simplified criteria of Samilson and Prieto[22] and received shoulder arthroplasty. According to the criteria, grade 4 inclusive of the narrowing of the glenohumeral joint along with sclerosis was excluded from the study. All patients in the anterior instability group were examined using computed tomography arthrography and had glenoid bone defects of less than 25%. Their lesions were reconstructed with suture anchors. The AC group did not have other associated lesions, and all patients underwent manipulation under anesthesia before surgery and arthroscopic capsular release. We excluded patients who did not have sufficient radiologic examination findings or who had a history of surgery, wound, fracture, tumor, or infection on the same side. This study used the AC group as the control group, instead of healthy persons without lesions. Two researchers (J.Y.K. and S.M.R.) analyzed the records of patients independently and performed radiologic evaluations.

Radiologic measurements

All angles were measured using the true AP view of the shoulder joint taken at most 3 months before surgery (Figs. 1 and 2). The true AP view was taken in the 20° caudal direction after putting the arm in a neutral position, straightening the elbow, pointing the thumb forward, and placing the patient's scapula against a radiographic cassette. Following the method suggested by Nyffeler et al,[21] the humeral

Table I Average values of radiologic parameters

	RCT	OA	Anterior instability	Adhesive capsulitis	*P* value
No. of patients	493	73	361	84	<.001*
Age, yr	61.1	72.3	26.4	52.4	<.001*
LAA, °	78.2	85.6	82.5	80.8	<.001*
AI	0.71	0.66	0.64	0.66	<.001*
CSA, °	34.2	29.8	32.1	32.1	<.001*
Y angle, °	76.7	82.8	74.1	73.8	<.001*
G angle, °	70.4	61.7	64.6	68.2	<.001*
YG angle, °	147.1	144.5	138.6	141.4	<.001*
R angle, °	52.9	48.0	54.8	53.1	<.001*

RCT, rotator cuff tear; *OA*, osteoarthritis; adhesive capsulitis; *LAA*, lateral acromial angle; *AI*, acromial index; *CSA*, critical shoulder angle.
* Statistically significant.

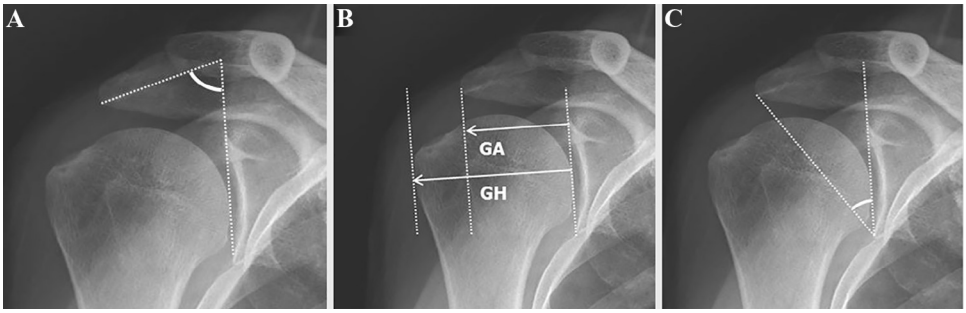

Figure 1 **(A)** The lateral acromial angle is assessed at the intersection of 2 lines representing the glenoid cavity and the acromion's undersurface. **(B)** The acromial index is calculated by dividing the distance of the glenoid plane to the lateral acromial border (*GA*) by the distance of the glenoid plane to the lateral margin of the humeral head (*GH*). **(C)** The critical shoulder angle is measured by drawing a line connecting the superior and inferior osseous margins of the glenoid cavity and then drawing a second line from the inferolateral border of the acromion, intersecting with the first line at the inferior glenoid margin. The angle between the 2 lines is the critical shoulder angle.

head was placed in the neutral position or rotated 20° internally at maximum, and the radiograph of the scapula was obtained within 20° of internal or external rotation.

The LAA was measured by calculating the angle between the line crossing the lower part of the acromion and the line connecting the upper end and lower end of the glenoid (Fig. 1, *A*).[1] The AI was measured by determining the distance from the surface of the glenoid to the outermost part of the acromion and dividing this by the distance from the surface of the glenoid to the outermost part of the greater tubercle (Fig. 1, *B*).[21] The CSA was measured by calculating the angle between the line connecting the upper end and lower end of the glenoid and the line from the lower end of the glenoid to the outermost part of the acromion (Fig. 1, *C*).[16]

The Y angle was measured by calculating the angle between the line connecting the central point of the humeral head and the lower end of the glenoid and the line linking the central point of the humeral head and the upper end of the glenoid (Fig. 2, *A*). The G angle was defined as the angle between the line connecting the central point of the humeral head and the upper end of the glenoid and the line linking the central point of the humeral head and the outermost side of the acromion (Fig. 2, *A*). The YG angle was defined as the angle between the line connecting the central point of the humeral head and the lower end of the glenoid and the line linking the central point of the humeral head and the outermost side of the acromion (Fig. 2, *A*). The R angle was defined as the angle between the line connecting the upper end and lower end of the glenoid and the line connecting the lower end of the glenoid and the central point of the humeral head (Fig. 2, *B*).

Statistical analyses

Statistical differences among the 4 groups were tested by conducting analysis of variance followed by the Scheffé post hoc test. The χ^2 test was conducted to test the frequency of various measurements such as age and other radiologic evaluations. The Pearson correlation test was carried out to evaluate the correlation between the radiologic measurements. Moreover, logistic regression analysis was performed to test whether the CSA and the new measurement method were good at predicting the size of RCTs, in which a small to medium tear was set as 0 and a large to massive tear was set as 1.

The intraclass correlation coefficient (ICC, 2-way mixed model for consistency) was calculated to evaluate the consistency between observers and between measurements of a single observer. An ICC of less than 0.01 was determined to be poor; 0.01 to 0.2, slight; greater than 0.2 to 0.4, fair; greater than 0.4 to 0.6, moderate; greater than 0.6 to 0.8, substantial; and greater than 0.8 to 1.0, almost perfect.[13] All statistical analyses were conducted using IBM SPSS Statistics for Windows (version 22.0; IBM, Armonk, NY, USA), and statistical significance was determined at $\alpha = .05$ unless stated otherwise.

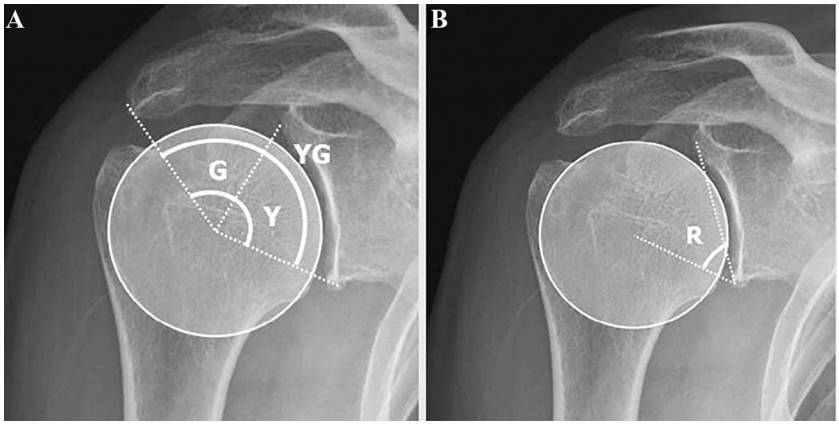

Figure 2 **(A)** The Y angle is measured by drawing a line connecting the superior margin of the glenoid cavity and humeral head center and then another line from the inferior margin of the glenoid cavity, intersecting with the first line at the humeral head center. The G angle is measured by drawing a line connecting the superior border of the glenoid and center of the humeral head and then another line from the acromion's lateral border, intersecting with the first line at the humeral head center. The YG angle is measured by drawing a line connecting the inferior margin of the glenoid cavity and humeral head center and then another line from the humeral head center and inferolateral border of the acromion, intersecting with the first line at the humeral head center. **(B)** The R angle is measured by drawing a line connecting the superior and inferior osseous margins of the glenoid cavity and then another line from the humeral head center, intersecting with the first line at the inferior glenoid margin. The angle between the 2 lines is the R angle.

Results

Of the patients, 703 underwent surgery at Kyung-Hee University Hospital and 308 underwent surgery at Chung-Ang University Hospital. There were 544 male and 467 female patients. The mean age of the patients was 55.2 years (range, 14-81 years). In the subgroup analysis, the mean age in the RCT group was 61.1 ± 8.6 years. The mean age of patients with OA was 72.3 ± 9.7 years, and that of patients with anterior instability, which was accompanied by Bankart lesions, was 26.4 ± 9.0 years. The mean age of patients with AC was 52.4 ± 10.3 years.

The ICCs of all radiologic evaluations were classified as almost perfect, with intraobserver ICCs of 0.97 for AI and CSA; 0.96 for LAA; 0.96 for R angle and YG angle; and 0.95 for Y angle and G angle and with interobserver ICCs of 0.94 for AI and LAA; 0.95 for CSA, YG angle, and R angle; and 0.96 for Y angle and G angle.

Radiologic parameters in 4 groups

Overall, age and variables in all angles were significantly different among the 4 groups ($P < .001$) (Table I). The post hoc analysis results for the LAA, AI, and CSA are presented in Table II. Among these 3 previously reported radiologic methods, only the CSA in the RCT group and OA group showed a statistically significant difference between the groups (Fig. 3).

The post hoc analysis results for the new radiologic parameters are shown in Table III. The Y angle in the RCT group (76.7° ± 6.8°) was smaller than that in the OA group (82.8° ± 12.4°) ($P < .001$). Moreover, it was larger than that in the anterior instability group (74.1° ± 5.3°) and that in the AC group (73.8° ± 6.7°) ($P < .001$). The Y angle in the OA group was larger than that in the 3 other groups ($P < .001$) (Fig. 4).

The G angle in the RCT group (70.4° ± 6.2°) was larger than that in the other groups ($P < .001$). At the same time, the G angle in the OA group (61.7° ± 12.3°) was significantly smaller than that in the other groups ($P < .001$) with the exception of the OA group versus the anterior instability group ($P = .024$) (Fig. 5).

The YG angle in the RCT group (147.1° ± 8.8°) was significantly larger than that in the anterior instability group (138.6° ± 8.6°) and that in the AC group (142.0° ± 8.8°) ($P < .001$), but it was not significantly different from that in the OA group (144.5° ± 11.3°) ($P = .147$). The YG angle in the OA group was significantly different only from that in the anterior instability group ($P = .001$) (Fig. 6).

The R angle in the RCT group (52.9° ± 3.6°) was significantly larger than that in the OA group (48.0° ± 7.8°) ($P < .001$) and significantly smaller than that in the anterior instability group (54.8° ± 4.3°) ($P < .001$). On the other hand, the R angle in the OA group was significantly smaller than that in the other groups ($P < .001$) (Fig. 7).

Correlations between CSA and new radiologic parameters

The Pearson correlation coefficient was used to evaluate the correlation between the CSA and the new method considering the humeral head (Table IV). The G angle showed the highest magnitude of the coefficient with the CSA in the RCT group (0.503) and OA group (0.719). In the anterior instability group and AC group, the AI showed the highest magnitude of the coefficient (0.759 and 0.834, respectively; all $P < .001$),

Table II *P* values for post hoc analysis of LAA, AI, and CSA

	RCT	OA	Anterior instability	Adhesive capsulitis
LAA	78.2° ± 6.8°	85.6° ± 9.0°	82.5° ± 7.0°	80.8° ± 7.2°
RCT	—	*P* <.001*	*P* <.001*	*P* = .134
OA	*P* <.001*	—	*P* = .023*	*P* <.001*
Anterior instability	*P* <.001*	*P* = .023*	—	*P* = .185
Adhesive capsulitis	*P* = .134	*P* <.001*	*P* = .185	—
AI	0.71 ± 0.08	0.66 ± 0.09	0.64 ± 0.07	0.66 ± 0.08
RCT	—	*P* <.001*	*P* <.001*	*P* <.001*
OA	*P* <.001*	—	*P* = .633	*P* = .977
Anterior instability	*P* <.001*	*P* = .633	—	*P* = .268
Adhesive capsulitis	*P* <.001*	*P* = .977	*P* = .268	—
CSA	34.2° ± 3.7°	29.8° ± 5.6°	32.1° ± 4.3°	32.1° ± 4.5°
RCT	—	*P* <.001*	*P* <.001*	*P* <.001*
OA	*P* <.001*	—	*P* = .001*	*P* = .004*
Anterior instability	*P* <.001*	*P* = .001*	—	*P* = .999
Adhesive capsulitis	*P* <.001*	*P* = .004*	*P* = .999	—

LAA, lateral acromial angle; *AI*, acromial index; *CSA*, critical shoulder angle; *RCT*, rotator cuff tear; *OA*, osteoarthritis.
* Statistically significant.

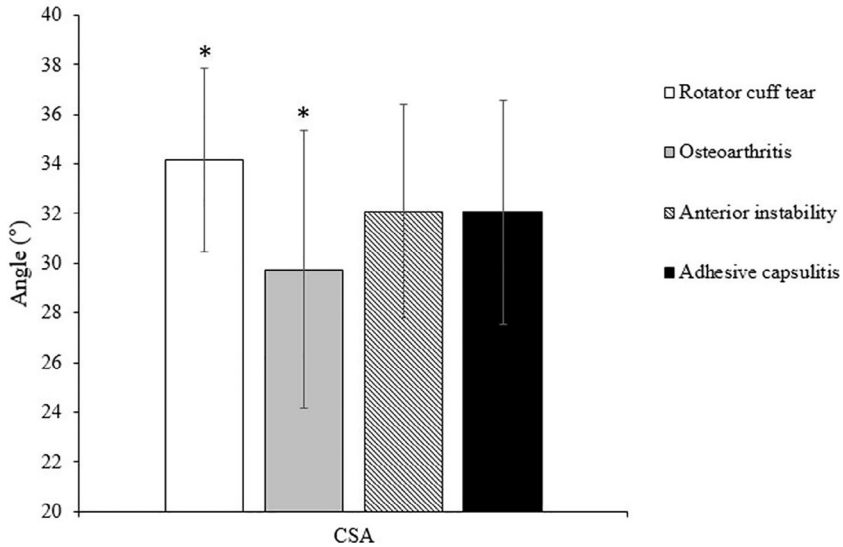

Figure 3 Radiologic parameter of critical shoulder angle (*CSA*) in 4 groups. The CSA in the rotator cuff tear group and osteoarthritis group showed significant differences compared with each of the other groups (*).

followed by the G angle (0.544 and 0.786, respectively; $P < .001$).

Correlations between radiologic parameters and RCT size

The RCT sizes were divided into 4 groups (small, medium, large, and massive tears). The correlation between the size of RCTs and radiologic parameters was examined (Table V, Fig. 8).

The LAA and RCT sizes were correlated at the entire patient level ($P = .038$). However, they were not significantly correlated at the size group level.

The CSA, YG angle, and R angle showed significant differences among all 4 groups ($P = .011$ for CSA, $P = .050$ for YG angle, and $P = .001$ for R angle). The *P* values for the post hoc analysis of those angles are shown in Table VI.

The G angle of a massive RCT was larger than that in the other groups by more than 2°, but the difference was not significant (70.1° ± 6.0°, 70.2° ± 5.6°, 70.4° ± 7.1°, and 72.7° ± 7.6° for small, medium, large, and massive tear sizes, respectively; $P = .065$). The AI and Y angle were not statistically different among the 4 groups ($P = .397$ and $P = .424$, respectively). Among the 4 groups classified by RCT size, the magnitude of the Pearson correlation coefficient was in the order of CSA ($r = 0.138$, $P = .002$), YG angle ($r = 0.120$,

Table III *P* values for post hoc analysis of Y, G, YG, and R angles

	RCT	OA	Anterior instability	Adhesive capsulitis
Y angle	76.7° ± 6.8°	82.8° ± 12.4°	74.1° ± 5.3°	73.8° ± 6.7°
RCT	—	*P* <.001*	*P* <.001*	*P* <.001*
OA	*P* <.001*	—	*P* <.001*	*P* <.001*
Anterior instability	*P* <.001*	*P* <.001*	—	*P* = .972
Adhesive capsulitis	*P* <.001*	*P* <.001*	*P* = .972	—
G angle	70.4° ± 6.2°	61.7° ± 12.3°	64.6° ± 7.0°	68.2° ± 7.3°
RCT	—	*P* <.001*	*P* <.001*	*P* <.001*
OA	*P* <.001*	—	*P* = .024*	*P* <.001*
Anterior instability	*P* <.001*	*P* = .024*	—	*P* = .054
Adhesive capsulitis	*P* <.001*	*P* <.001*	*P* = .054	—
YG angle	147.1° ± 8.8°	144.5° ± 11.3°	138.6° ± 8.6°	142.0° ± 8.8°
RCT	—	*P* = .147	*P* <.001*	*P* <.001*
OA	*P* = .147	—	*P* = .001*	*P* = .282
Anterior instability	*P* <.001*	*P* = .001*	—	*P* = .079
Adhesive capsulitis	*P* <.001*	*P* = .282	*P* = .079	—
R angle	52.9° ± 3.6°	48.0° ± 7.8°	54.8° ± 4.3°	53.1° ± 3.6°
RCT	—	*P* <.001*	*P* <.001*	*P* = .873
OA	*P* <.001*	—	*P* <.001*	*P* <.001*
Anterior instability	*P* <.001*	*P* <.001*	—	*P* = .072
Adhesive capsulitis	*P* = .873	*P* <.001*	*P* = .072	—

RCT, rotator cuff tear; *OA*, osteoarthritis.
* Statistically significant.

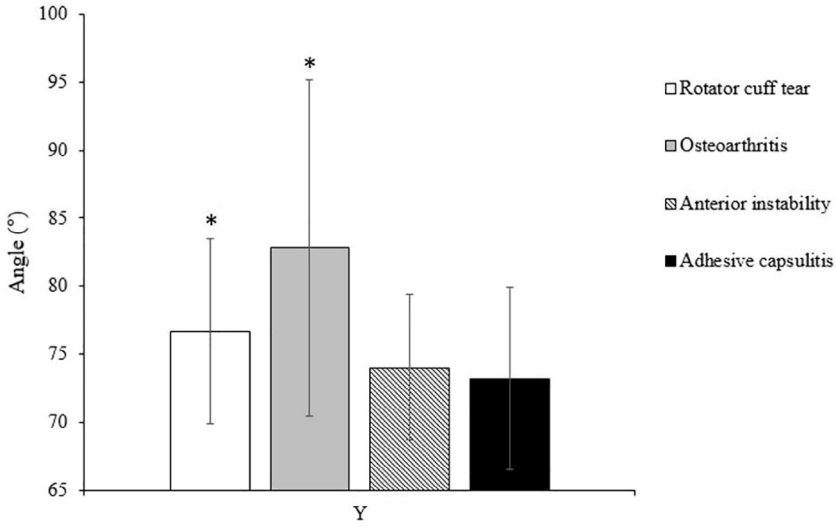

Figure 4 Radiologic parameter of Y angle in 4 groups. The Y angle in the rotator cuff tear group and osteoarthritis group showed significant differences compared with each of the other groups (*).

P = .008), R angle (*r* = –0.113, *P* = .012), and G angle (*r* = 0.093, *P* = .038).

Logistic regression of CSA and new radiologic parameters in each group

In the RCT group, the occurrence of large and massive tear sizes increased with a larger CSA, Y angle, G angle, and YG angle. The risk of occurrence was in the order of CSA, G angle, YG angle, and Y angle (odds ratios [ORs] = 1.148 [*P* < .001], 1.124 [*P* < .001], 1.094 [*P* < .001], and 1.026 [*P* = .004], respectively). The risk of occurrence increased with a smaller R angle (OR = 0.967, *P* = .014).

In the OA group, the risk of occurrence increased with a larger Y angle (OR = 1.127, *P* < .001). The risk of occurrence increased with a smaller CSA, G angle, and R angle. The risk of occurrence was in the order of G angle, CSA, and R angle (ORs = 0.915, 0.836, and 0.768, respectively; *P* < .001).

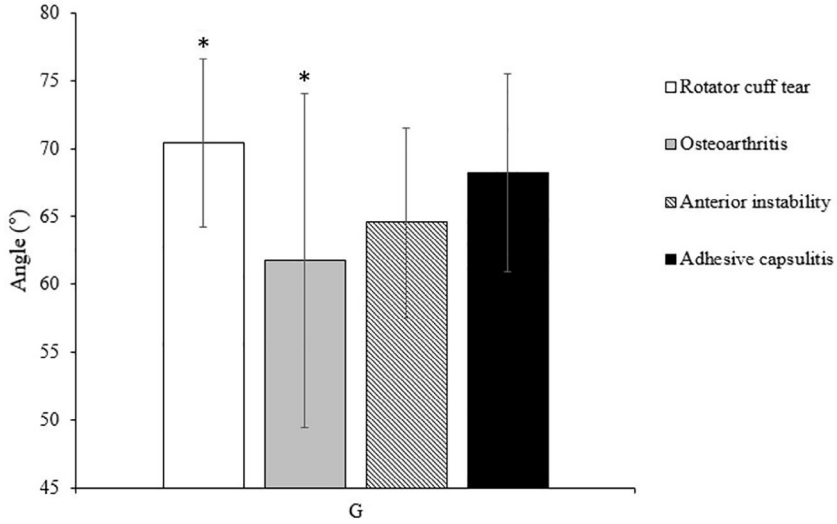

Figure 5 Radiologic parameter of G angle in 4 groups. The G angle of the rotator cuff tear group and osteoarthritis group showed significant differences compared with each of the other groups (*).

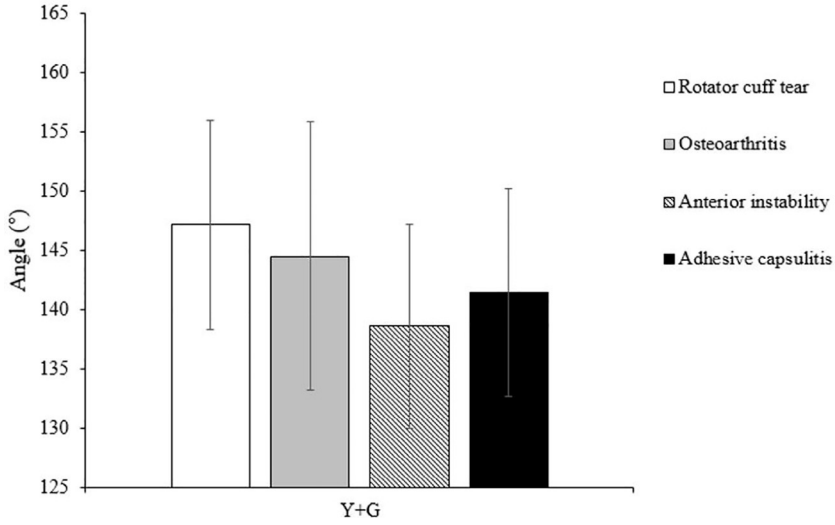

Figure 6 Radiologic parameter of YG angle in 4 groups. The YG angle in the rotator cuff tear group showed a significant difference compared with that in the anterior instability group and adhesive capsulitis group, but it was not different from that in the osteoarthritis group. The YG angle in the osteoarthritis group was significantly different only from that in the anterior instability group.

Discussion

Many studies have been carried out to evaluate the relationship between RCTs and bone morphology by using simple radiography. Conventional studies examined the correlation of RCTs with acromial shape,[10] AI,[21] acromial tilt,[12] and lateral extension including the LAA.[1] However, recent studies have focused on the CSA as a measure to determine the occurrence of RCTs and OA.[16-18]

The CSA was first proposed by Moor et al[16] to overcome the limitations of the AI proposed by Nyffeler et al,[21] and it is meaningful because it also considers the glenoid inclination. Moor et al[16] measured the CSA in 94 patients free of symptoms, 102 patients with RCTs without OA, and 102 patients with OA without RCTs. They showed that 84% of patients with a CSA greater than 35° had RCTs and that 93% of patients with a CSA lower than 30° had OA. A previous simulation study[9] and 3-dimensional computational study[25] reported that a large CSA acted in the vertical force direction on the deltoid during initial abduction, resulting in increased shear force and instability of the joint. Moreover, the more abduction, the more force is applied to the deltoid toward the glenoid. It was also indicated that excessive loading was applied to the supraspinatus, an initial abductor, to maintain joint stability owing to different vector directions of the deltoid and supraspinatus during initial abduction.[9,25] Other studies revealed that a smaller CSA would decrease the moment arm of the deltoid and increase loading on the deltoid

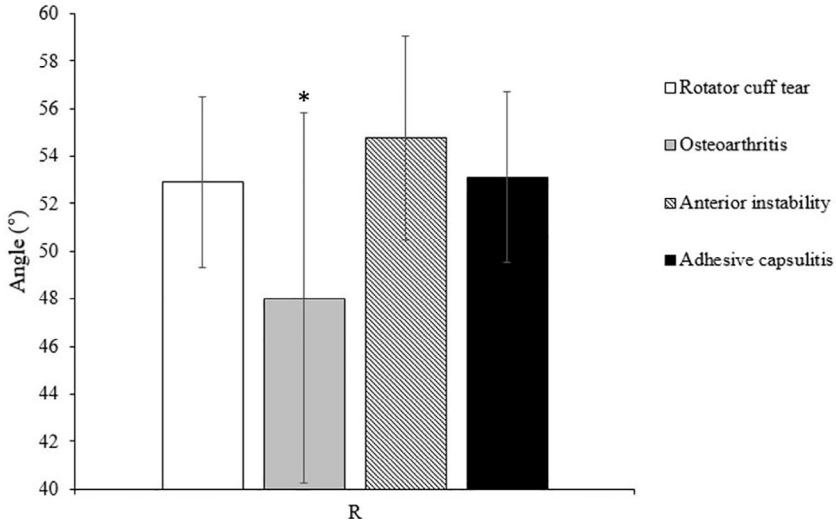

Figure 7 Radiologic parameter of R angle in 4 groups. The R angle of the rotator cuff tear group showed a significant difference compared with that in the osteoarthritis group and anterior instability group. The R angle in the osteoarthritis group was significantly smaller than that in the other groups (*).

Table IV Pearson correlation coefficients between CSA and new radiologic parameters

CSA	LAA	AI	Y angle	G angle	YG angle	R angle
RCT						
Pearson correlation coefficient	−0.179	0.416	0.045	0.503	0.389	0.058
P value	<.001*	<.001*	.202	.009*	.004*	.195
OA						
Pearson correlation coefficient	−0.373	0.487	−0.640	0.719	0.083	0.335
P value	.001*	<.001*	<.001*	<.001*	.483	.004*
Anterior instability						
Pearson correlation coefficient	−0.405	0.759	−0.033	0.544	0.375	0.129
P value	<.001*	<.001*	.765	<.001*	<.001*	.256
Adhesive capsulitis						
Pearson correlation coefficient	−0.540	0.834	0.057	0.786	0.672	0.303
P value	<.001*	<.001*	.604	<.001*	<.001*	.005*

CSA, critical shoulder angle; *LAA*, lateral acromial angle; *AI*, acromial index; *RCT*, rotator cuff tear; *OA*, osteoarthritis.
* Statistically significant.

to increase joint reaction force on the glenohumeral joint.[16,26] Moreover, they reported that the glenohumeral joint received higher loading because the vector of the deltoid and supraspinatus showed a synergistic effect in the same direction of the vector in a small CSA.[16,26] Consequently, this induced OA with decreasing loading on the rotator cuff.[16,26] Measurement of the CSA is accepted as the etiology of different shoulder lesions or a factor affecting the outcome of RCT treatment based on these theoretical backgrounds.

The CSA has been applied in many recent studies,[2,4,5,7,8,28] and some surgeons have performed lateral acromioplasty in patients with RCTs.[11] In our study, the CSA in patients with RCTs was 34.2°, which was larger than that in patients with OA (29.8°). The results of this study agree with the results of Moor et al,[16] showing that the former was 38.0° and the latter was 28.1° on average.

Table V Average values of radiologic parameters by rotator cuff tear size

	Small	Medium	Large	Massive	*P* value
No. of patients	133	288	85	47	<.001*
LAA, °	78.1	78.7	77.7	76.5	.038*
AI	0.70	0.70	0.72	0.71	.397
CSA, °	33.8	34.0	34.5	35.7	.011*
Y angle, °	75.9	76.8	77.2	77.4	.424
G angle, °	70.1	70.2	70.4	72.7	.065
YG angle, °	146.0	147.0	147.7	150.1	.050*
R angle, °	52.8	53.4	52.6	51.2	.001*

LAA, lateral acromial angle; *AI*, acromial index; *CSA*, critical shoulder angle.
* Statistically significant.

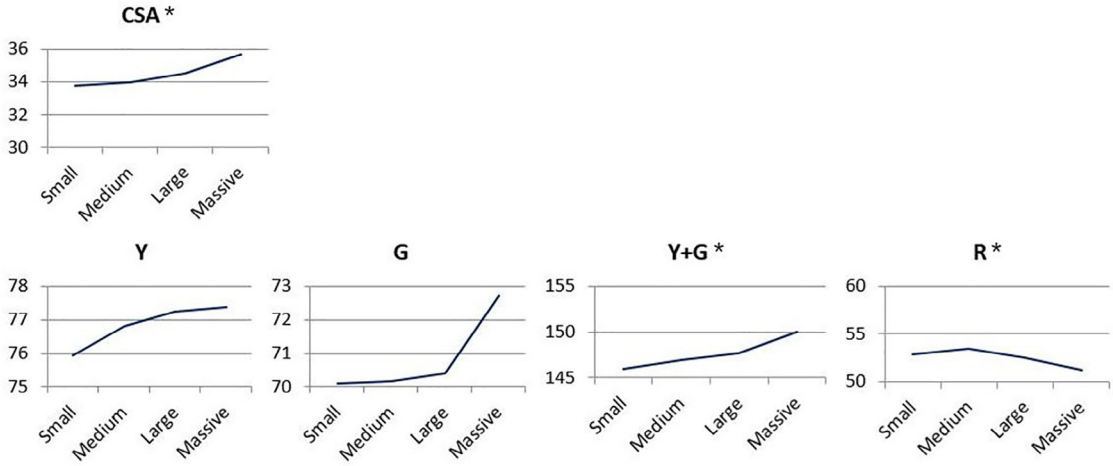

Figure 8 Correlations of critical shoulder angle (*CSA*) and new radiologic parameters (Y, G, YG, and R angles) with rotator cuff tear sizes. *Significant difference compared with the other 3 groups.

Table VI *P* values for post hoc analysis of CSA, YG angle, and R angle on correlation with rotator cuff tear sizes

	Small	Medium	Large	Massive
CSA				
Mean	33.8° ± 3.7°	34.0° ± 3.7°	34.5° ± 3.6°	35.7° ± 3.9°
P value vs massive	.022*	.037*	.370	—
YG angle				
Mean	150.1° ± 9.5°	147.7° ± 9.0°	147.0° ± 8.7°	146.0° ± 8.6°
P value vs massive	.034*	.122	.424	—
R angle				
Mean	52.8° ± 3.5°	53.4° ± 3.7°	52.6° ± 3.8°	51.2° ± 2.8°
P value vs massive	.034*	.001*	.159	—

CSA, critical shoulder angle.
* Statistically significant.

The interactions between the glenoid of the scapula and the humeral head, as well as their anatomic elements, are important to the glenohumeral joint as much as the anatomy of the scapula is to it. However, the CSA only considers the anatomic elements of the scapula, and consequently, it is limited in explaining the etiology of shoulder diseases. In fact, there have been several controversies including Bjarnison et al,[2] that the CSA was correlated with OA, but not correlated with RCTs. The LAA has been used in a large number of studies, but it only considers the anatomic elements of the scapula.[1] The AI takes into consideration the anatomic elements of the greater tubercle of the humerus, whereas previous studies indicated that patients with RCTs showed a large AI.[15,21] However, because the AI requires 2 measurements and calculation to obtain a result, this might be more prone to error. In addition, the value may deviate if the radiograph is taken while the humeral head is rotated.[23] Furthermore, patients with RCTs may have erosion of the greater tubercle. Consequently, the AI can have limitations because the distance to the greater tubercle is important to the AI.[14]

The objective of this study was to propose a new radiologic evaluation method considering the anatomic elements of the humeral head and the scapula. It included the anatomic shape of the humeral head to overcome the limitations of the CSA and LAA and used the central point of the humeral head, instead of the greater tubercle, to overcome the limitations of the AI, which could be affected by the rotation of the humerus. It measured the Y, G, YG, and R angles by using the central point of the humeral head. The new measure showed a high correlation with RCTs and OA, as much as with the CSA. The G angle, among the new measurements, increased with a higher CSA, and the correlation coefficient between the CSA and G angle was higher than that between the CSA and AI, which is widely used in patients with RCTs and OA.

However, contrary to our expectation, the correlation coefficient between the CSA and RCTs was higher than that between the new measurements. Moreover, the CSA was highly correlated with the new radiologic evaluation method. In particular, the G angle revealed good correlations with RCTs ($r = 0.503$), OA ($r = 0.719$), anterior instability ($r = 0.544$), and AC ($r = 0.786$). The results confirmed that the CSA reflects the anatomic elements of the humeral head, although it does not include the humeral head measurement. The results

of this study were contrary to the assumption that the CSA had limitations because it did not consider the humeral head, and the new evaluation method considering the humeral head was needed.

Although the CSA had the highest correlation with RCTs, it was noteworthy that the new radiologic evaluation method considering the humeral head was closely correlated with each lesion, as expected. The Y angle, G angle, and R angle of patients with RCTs were significantly different from those in patients with other lesions. Moreover, the Y angle of patients with RCTs was smaller than that in patients with OA, and the G angle and R angle were larger than those in patients with OA. The Y angle can be decreased because RCTs move the humeral head upward, unlike OA, which moves the center of the humeral head inward with articular wear. The G angle in the RCT group was the largest among all groups, and this could be because the coverage of the RCT group's acromion was larger than that in the other groups. The Y angle in the OA group was the largest among all groups. This could be the result of moving the center point of the humeral head to the medial side, as the humeral head moves toward the glenoid side owing to degenerative cartilage wear. The G angle in the OA group was smaller than that in the other groups, and this could be a result of the small CSA and the small lateral extension of the acromion. The R angle in the OA group was the smallest among the 4 groups, which could occur because the center of the humeral head was medialized. Therefore, consideration of both the CSA and the new method will help surgeons diagnose and treat patients, instead of using them as separate radiologic determination methods.

This study showed that a larger CSA would increase the size of RCTs, which agreed with the results of previous studies.[17,25] It was confirmed that the CSA had a higher correlation coefficient than other angle measurements, including the proposed new evaluation method. The results of this study were similar to those of the biomechanical study of Gerber et al,[9] who reported that a larger CSA induced the excessive load on the supraspinatus tendon during active abduction, and the study of Blonna et al,[3] who showed that the CSA in the group with supraspinatus and infraspinatus tears (40° ± 3.5°) was 4° larger than that in the group with isolated supraspinatus tears (36° ± 3°).

It was interesting that the new evaluation method considering the humerus was also related to the size of RCTs. The YG angle and R angle were significantly different based on the size of RCTs. Moreover, in the 4 groups classified by RCT size, the Pearson correlation coefficient was in the order of CSA ($r = 0.138$, $P = .002$), YG angle ($r = 0.120$, $P = .008$), R angle ($r = –0.113$, $P = .012$), and G angle ($r = 0.093$, $P = .038$). The size was not significantly correlated with the LAA and AI, which were frequently used in the literature. Previous studies suggested that the extended lateral acromion would put excess loading on the rotator cuff because it would require more force from the supraspinatus tendon to place the humerus at the center of the shoulder joint, owing to the upward deltoid vector.[24,25] It was speculated that a higher YG angle would turn the deltoid vector more upward and, consequently, induce an RCT. The R angle in the massive tear size group was smaller than that in the small and medium tear size groups, and there could be several reasons for this: First, if the lateral extension of the acromion is assumed to be constant, the coverage of the acromion increases with a smaller R angle, indicating that the central point of the humeral head is located more medially. Second, it was believed that a larger RCT size would increase the association with OA and be closer to the R angle in the OA group because previous studies reported that large tears and chronic tears would be associated with various local inflammatory factors that would induce arthritis in the glenohumeral joint, although small RCTs did not change the glenohumeral joint.[20]

This study compared patients with anterior instability or patients with AC, as controls, in different age groups. The new radiologic evaluation method, particularly the G angle, was highly correlated with the CSA in patients with anterior instability or AC. Furthermore, the CSA, Y angle, and G angle in the anterior instability group and AC group were significantly different from those in the RCT and OA groups, showing that the CSA and the new radiologic evaluation method reflected the lesions in patients with RCTs and OA well.

This was a retrospective cohort study, and it could have a bias. Moreover, it is difficult to apply the results of this study to "non-diseased" persons because this study did not target the general population. However, our study tested 1011 patients, and this is one of its main strengths. In addition, this study was meaningful in the aspect that it suggested a new radiologic evaluation method considering both the humeral head and the scapula.

Conclusions

Among simple radiographic evaluation methods including the humeral head, the Y angle, G angle, and R angle reflected the correlation with lesions in patients with RCTs or OA well. The CSA showed the highest correlation coefficient with the size of RCTs among all measurement methods. The results of this study suggested that the CSA is an important evaluation method reflecting the anatomic shape of the humeral head, even though it does not measure the humeral head.

Disclaimer

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References

1. Banas MP, Miller RJ, Totterman S. Relationship between the lateral acromion angle and rotator cuff disease. J Shoulder Elbow Surg 1995;4:454-61.
2. Bjarnison AO, Sorensen TJ, Kallemose T, Barfod KW. The critical shoulder angle is associated with osteoarthritis in the shoulder but not rotator cuff tears: a retrospective case-control study. J Shoulder Elbow Surg 2017;26:2097-102. http://dx.doi.org/10.1016/j.jse.2017.06.001
3. Blonna D, Giani A, Bellato E, Mattei L, Calo M, Rossi R, et al. Predominance of the critical shoulder angle in the pathogenesis of degenerative diseases of the shoulder. J Shoulder Elbow Surg 2016;25:1328-36. http://dx.doi.org/10.1016/j.jse.2015.11.059
4. Chalmers PN, Salazar D, Steger-May K, Chamberlain AM, Yamaguchi K, Keener JD. Does the critical shoulder angle correlate with rotator cuff tear progression? Clin Orthop Relat Res 2017;475:1608-17. http://dx.doi.org/10.1007/s11999-017-5249-1
5. Cherchi L, Ciornohac JF, Godet J, Clavert P, Kempf JF. Critical shoulder angle: measurement reproducibility and correlation with rotator cuff tendon tears. Orthop Traumatol Surg Res 2016;102:559-62. http://dx.doi.org/10.1016/j.otsr.2016.03.017
6. DeOrio JK, Cofield RH. Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. J Bone Joint Surg Am 1984;66:563-7.
7. Garcia GH, Liu JN, Degen RM, Johnson CC, Wong AC, Dines DM, et al. Higher critical shoulder angle increases the risk of retear after rotator cuff repair. J Shoulder Elbow Surg 2017;26:241-5. http://dx.doi.org/10.1016/j.jse.2016.07.009
8. Gerber C, Catanzaro S, Betz M, Ernstbrunner L. Arthroscopic correction of the critical shoulder angle through lateral acromioplasty: a safe adjunct to rotator cuff repair. Arthroscopy 2018;34:771-80. http://dx.doi.org/10.1016/j.arthro.2017.08.255
9. Gerber C, Snedeker JG, Baumgartner D, Viehöfer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: a biomechanical analysis. J Orthop Res 2014;32:952-7. http://dx.doi.org/10.1002/jor.22621
10. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res 1990:92-6.
11. Katthagen JC, Marchetti DC, Tahal DS, Turnbull TL, Millett PJ. The effects of arthroscopic lateral acromioplasty on the critical shoulder angle and the anterolateral deltoid origin: an anatomic cadaveric study. Arthroscopy 2016;32:569-75. http://dx.doi.org/10.1016/j.arthro.2015.12.019
12. Kitay GS, Iannotti JP, Williams GR, Haygood T, Kneeland BJ, Berlin J. Roentgenographic assessment of acromial morphologic condition in rotator cuff impingement syndrome. J Shoulder Elbow Surg 1995;4:441-8.
13. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
14. Melean P, Lichtenberg S, Montoya F, Riedmann S, Magosch P, Habermeyer P. The acromial index is not predictive for failed rotator cuff repair. Int Orthop 2013;37:2173-9. http://dx.doi.org/10.1007/s00264-013-1963-9
15. Miyazaki AN, Itoi E, Sano H, Fregoneze M, Santos PD, da Silva LA, et al. Comparison between the acromion index and rotator cuff tears in the Brazilian and Japanese populations. J Shoulder Elbow Surg 2011;20:1082-6. http://dx.doi.org/10.1016/j.jse.2011.04.028
16. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint?: a radiological study of the critical shoulder angle. Bone Joint J 2013;95-B:935-41. http://dx.doi.org/10.1302/0301-620X.95B7.31028
17. Moor BK, Röthlisberger M, Müller DA, Zumstein MA, Bouaicha S, Ehlinger M, et al. Age, trauma and the critical shoulder angle accurately predict supraspinatus tendon tears. Orthop Traumatol Surg Res 2014;100:489-94. http://dx.doi.org/10.1016/j.otsr.2014.03.022
18. Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. J Shoulder Elbow Surg 2014;23:536-41. http://dx.doi.org/10.1016/j.jse.2013.11.008
19. Neer CS 2nd, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. J Bone Joint Surg Am 1982;64:319-37.
20. Noh KC, Park SH, Yang CJ, Lee GW, Kim MK, Kang YH. Involvement of synovial matrix degradation and angiogenesis in oxidative stress-exposed degenerative rotator cuff tears with osteoarthritis. J Shoulder Elbow Surg 2018;27:141-50. http://dx.doi.org/10.1016/j.jse.2017.08.007
21. Nyffeler RW, Werner CM, Sukthankar A, Schmid MR, Gerber C. Association of a large lateral extension of the acromion with rotator cuff tears. J Bone Joint Surg Am 2006;88:800-5. http://dx.doi.org/10.2106/JBJS.D.03042
22. Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. J Bone Joint Surg Am 1983;65:456-60.
23. Singleton N, Agius L, Andrews S. The acromiohumeral centre edge angle: a new radiographic measurement and its association with rotator cuff pathology. J Orthop Surg (Hong Kong) 2017;25:2309499017727950. http://dx.doi.org/10.1177/2309499017727950
24. Uhthoff HK, Loehr JW. Calcific tendinopathy of the rotator cuff: pathogenesis, diagnosis, and management. J Am Acad Orthop Surg 1997;5:183-91.
25. Viehofer AF, Gerber C, Favre P, Bachmann E, Snedeker JG. A larger critical shoulder angle requires more rotator cuff activity to preserve joint stability. J Orthop Res 2016;34:961-8. http://dx.doi.org/10.1002/jor.23104
26. Viehofer AF, Snedeker JG, Baumgartner D, Gerber C. Glenohumeral joint reaction forces increase with critical shoulder angles representative of osteoarthritis—A biomechanical analysis. J Orthop Res 2016;34:1047-52. http://dx.doi.org/10.1002/jor.23122
27. Walch G, Edwards TB, Boulahia A, Nove-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. J Shoulder Elbow Surg 2005;14:238-46. http://dx.doi.org/10.1016/j.jse.2004.07.008
28. Watling JP, Sanchez JE, Heilbroner SP, Levine WN, Bigliani LU, Jobin CM. Glenoid component loosening associated with increased critical shoulder angle at midterm follow-up. J Shoulder Elbow Surg 2018;27:449-54. http://dx.doi.org/10.1016/j.jse.2017.10.002