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Greater tuberosity angle and critical shoulder angle according to the delamination patterns of rotator cuff tear

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ABSTRACT

The purpose was to evaluate the relationship between GTA, CSA, and the delamination patterns of RCTs. This study included 315 patients with RCTs from 2014 to 2018, retrospectively. The subjects were divided into 5 groups: Group A, control group; Group B, non-delaminated tear; Group C, delaminated tear with equally retraction of articular and bursal layer; Group D, articular layer more retracted delaminated tear, and Group E, bursal layer more retracted delaminated tear. In conclusion, large GTA and CSA were associated with rotator cuff tears. However, there was no difference of GTA and CSA according to the delamination patterns.

1. Introduction

Degenerative rotator cuff tear is one of a common disorder in the shoulder. Delamination is a horizontal and partial thickness split of the tendon substance between layers of a ruptured rotator cuff.[1,2] A widely ranging incidence of 38–92% has been reported, but the precise cause of delamination is still unknown.[1–3] Sonnabend et al.[4] demonstrated through a histological study that laminated tears of the rotator cuff generally occurred between two layers of different collagen fiber orientations.

However, there is no settled etiology of rotator cuff tears (RCTs) until now. There has been classically described as intrinsic, extrinsic, or a complex of both as mechanisms of Rotator cuff tendinopathy[5] Chronic overload on rotator cuff tendon was suggested as the factor among the risk factors of the diseases.[6] It was reported on many studies that supraspinatus tendon has different tensile stress between bursal side and articular side in itself. And the delamination and partial thickness tear might be caused by maximal stress concentration on the articular side of the supraspinatus tendon.[7–9]

High concentration of stress tensile was observed at the articular side and it might be related with progression of the tear, even when the 3 types of partial tear were existed.[9]

Anatomical morphology of the RCTs has beed studied recently. In 2013, Moor et al. introduced parameter called critical shoulder angle (CSA) as quantifying the relationship between glenoid and acromion and suggested the relationship with osteoarthritis and RCTs of the shoulder.[10] In 2014, Gerber et al. showed on biomechanical study that the tensile load on the supraspinatus tendon is greater as the larger of the CSA for stabilization of the humeral head within the glenoid.[11]

In 1972, Neer et al. proposed subacromial impingement as another potential risk factor.[12] Moreover, it was found in many other studies that hooked acromion is more likely to associated with RCTs.[13,14] Furthermore, there is controversy about acromial spur as a cause or the result of RCTs.[15] Subacromial spur can be produced by traction load of coracoacromial arch, which is required for superior stability of humeral head when RCTs present.[15] But, In the rat study, Experimental subacromial impingement caused bursal-sided Partial-thickness rotator cuff tears (PTRCTs).[16] Anatomical factors associated with subacromial impingement were associated with bursal-sided PTRCTs.[17]

Greater tuberosity angle (GTA) was introduced first in 2018 for new predictor.of RCTs. The angle is made by two lines, first line which pass through center of humeral head and parallel to diaphysis of the humerus and second line which is made by connection of the most superolateral edge of greater tuberosity and upper border of the humeral head. The author described relationship between high GTA and RCTs needs to be elucidated with exact underlying cause. Hence, in patients with high GTA, subacromial impingement might be existed with an extrinsic point of view. Or with an intrinsic point of view higher tensile load might be needed because of more divergent from the deltoid.[18]

However, the analysis of GTA and CSA according to delamination

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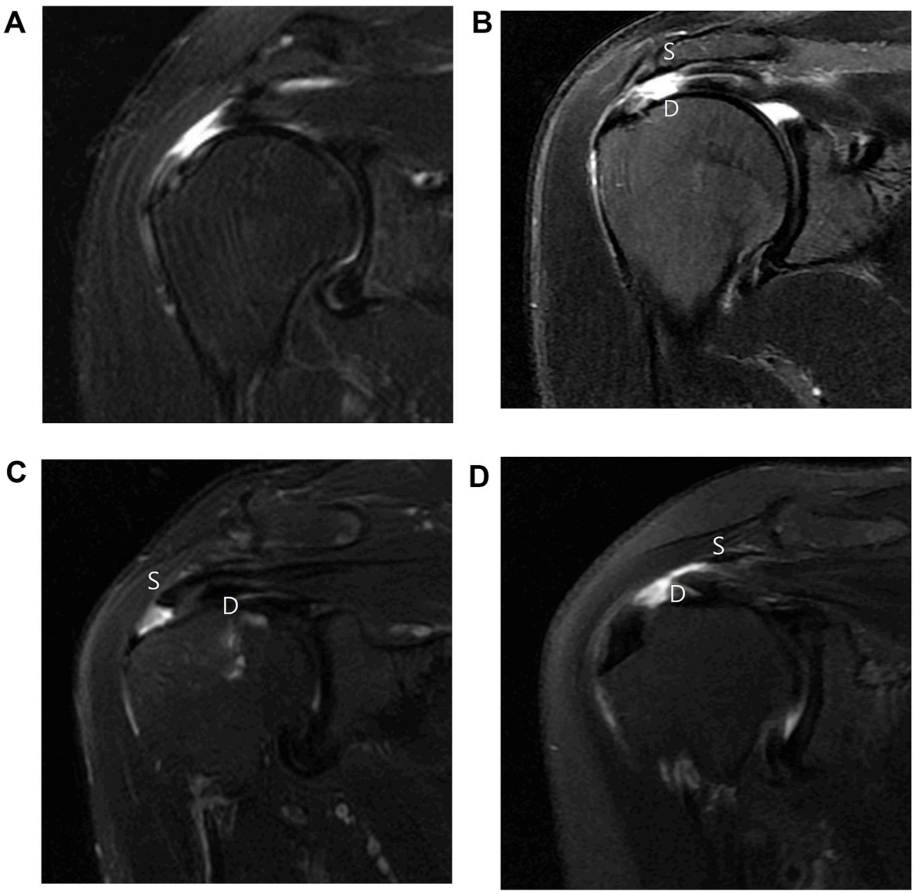

Fig. 1. (A) Group B, non-delaminated tear; (B) Group C, delaminated tear with the deep layer equally retracted to the superficial layer; (C) Group D, delaminated tear with the deep layer more medially retracted than the superficial layer; (D) Group E, delaminated tear with the superficial layer more medially retracted than the deep layer. D, Deep layer; S, Superficial layer.

Table 1
Reliability of grouping and radiographic measurements.

Measurement position	ICC (KH vs KH)	ICC (JHY vs JHY)	ICC (KH vs JHY)
Grouping of delamination patterns			0.88
Critical shoulder angle	0.91	0.90	0.90
Greater tuberosity angle	0.92	0.88	0.89

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

patterns of the RCTs is limited, the purpose of the present study was to evaluate the relationship between GTA, CSA, and delamination patterns of the RCTs.

2. Material and methods

After obtaining ethical approval (DKUH 2019-01-010), we retrospectively identified 315 patients of our institution to be included in this study from 2014 to 2018. Sixty-three patients who had normal rotator cuff tendons and muscles according to MRI were also enrolled as the control group, 252 patients were diagnosed with RCTs by a musculoskeletal radiologist using the same type of MRI for evaluation within same conditions. In the present study, the subjects were divided into five groups with a modification of Choo et al.'s method[19]: Group A, control group; Group B, non-delaminated tear; Group C, delaminated tear with the articular layer equally retracted to the bursal layer; Group D, articular layer more medially retracted delaminated tear, and Group E, bursal layer more medially retracted delaminated tear. (Fig. 1). The delaminated RCTs were classified by two orthopedic shoulder surgeons (K.H. and J.H.Y.). The cases in which divisions were not agreed upon by the two orthopedic surgeons were excluded, although the interobserver

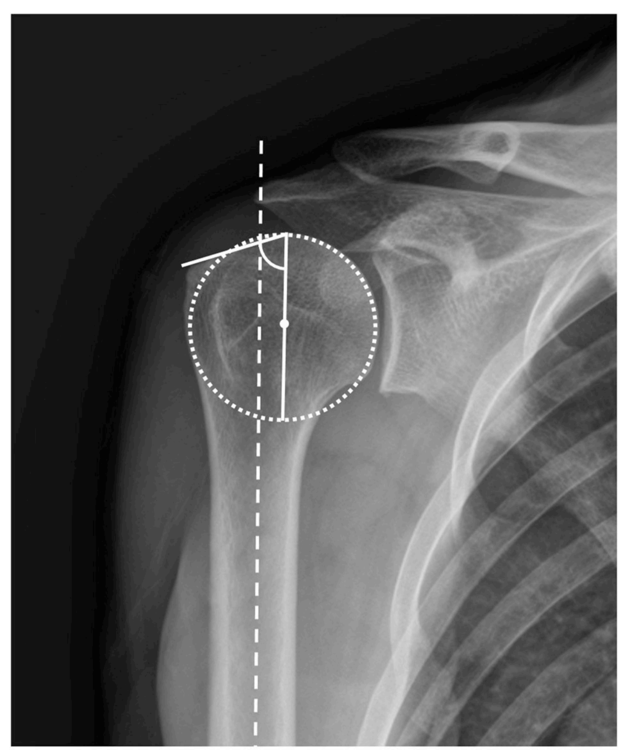

Fig. 2. The angles between a line connecting the superior and inferior osseous margins of the glenoid cavity and a line connecting the inferior osseous margins of the glenoid cavity and the inferolateral border of the acromion were measured as the critical shoulder angle.

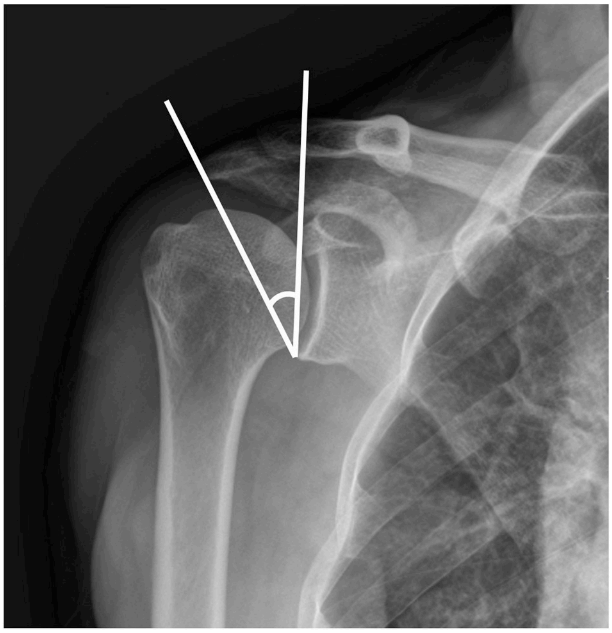

Fig. 3. The angles between a line that parallel line to the diaphyseal axis passing though the humeral head center of rotation and a line connecting the upper border of the humeral head to the most superolateral edge of the greater tuberosity were measured as the greater tuberosity angle.

correlation had an almost perfect agreement (k = 0.88) (Table 1). The exclusion criteria were shoulder instability, neuromuscular disease, concealed interstitial delamination, partial-thickness RCTs, and previous surgery on the affected shoulder. Patient's information including sex, age, weight, height, dominant hand, smoking history and body mass index was obtained from medical records.

3. Measurement of the GTA and the CSA

The GTA was measured from the radiograph, in use of method according to Cunningham et al.[18] The angle is made by two lines, first line which pass through center of humeral head and parallel to diaphysis of the humerus and second line which is made by connection of the most superolateral edge of greater tuberosity and upper border of the humeral head (Fig. 2).

True Anterior-posterior radiographs were used for measuring CSA by the method which was described by Moor et al.[10] CSA is formed by two lines, first is drawn from glenoid's superior and inferior border and second is drawn from lateral aspect of the acromion and inferior border of the glenoid. (Fig. 3).

For this study, two shoulder surgeons (K.H. and J.H.Y) independently measured both the GTA and the CTA at 2 different times separated by 1 month. The observers were blinded to group identities and the each other's measurements. Both inter-observer and intra-observer reliabilities for both GTA and CSA measurement were almost perfect agreements (Table 1).

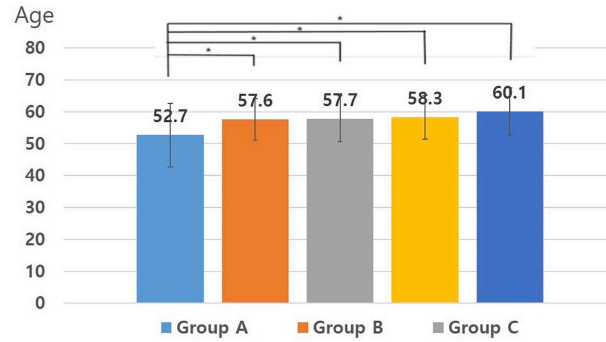

Fig. 4. Comparison of the patients' age. Statistically significant differences are indicated by brackets and an asterisk.

4. Statistical methods

Differences in the GTAs and CSAs among the control group and RCTs groups were evaluated with independent student t-test. For the evaluation according to the delaminated patterns, the five groups were examined using one-way ANOVA test and post hoc analysis with Tukey's test. The weighted kappa coefficient was used to estimate the interobserver reliability and the intraobserver reliability for measurement of CSA and GTA. The 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 accomplished using SPSS version 21.0 (SPSS Inc., Chicago, Il, USA). Multivariable-adjusted analyses for the occurrence of RCTs delamination patterns was examined using logistic regression analysis. Statistical significance was set at $p < 0.05$.

5. Results

5.1. Demographic data

Of the 315 patients included in this study, there were 63 patients with control group (Group A), 67 patients with non-delaminated tear (Group B), 51 patients delaminated tear with the articular layer equally retracted to the bursal layer (Group C), 118 patients with articular layer more medially retracted delaminated tear (Group D), and 16 patients with bursal layer more medially retracted delaminated tear (Group E). There was no statistical significant difference among groups in demographic data in exception of age. (Table 2, Fig. 4).

5.2. Radiologic measurements

The mean GTA of control group was 70.8° ± 4.9° and that of RCTs groups (Group B, C, D, and E) was 73.2° ± 5.0°, the GTA of RCTs groups was significantly larger than control group (p = 0.001).

Table 2
Demographic data.

	Group A (n = 63)	Group B (n = 67)	Group C (n = 51)	Group D (n = 118)	Group E (n = 16)	p- value
Age (Mean ± SD)	52.7 ± 9.9	57.6 ± 6.6	57.7 ± 7.2	58.3 ± 6.9	60.1 ± 7.4	< 0.001
Sex (Male/Female)	46/17	41/26	27/24	68/50	7/9	N.S.
Right arm/Left arm	37/26	50/17	33/18	88/30	13/3	N.S.
Weight (kg, Mean ± SD)	69.1 ± 12.2	67.0 ± 11.2	64.7 ± 10.2	65.4 ± 9.3	62.3 ± 7.3	N.S.
Height (cm, Mean ± SD)	163.9 ± 9.8	162.2 ± 9.8	161.4 ± 9.0	161.8 ± 8.2	159.3 ± 7.6	N.S.
Body mass index (Mean ± SD)	25.7 ± 3.2	25.5 ± 3.9	24.8 ± 3.1	24.9 ± 2.8	24.6 ± 2.9	N.S.
Smoking/Non-smoking	17/46	20/47	7/44	33/85	4/12	N.S.

N.S. non-significant.

Table 3
Comparison of radiographic measurements.

	Group A (n = 63)	Group B (n = 67)	Group C (n = 51)	Group D (n = 118)	Group E (n = 16)	p- value
Critical shoulder angle (Mean ± SD)	32.5 ± 4.3	35.2 ± 3.6	34.9 ± 4.1	34.8 ± 3.9	34.4 ± 3.1	< 0.001
Greater tuberosity angle (Mean ± SD)	70.8 ± 4.9	72.9 ± 4.9	74.1 ± 4.9	73.1 ± 5.0	72.4 ± 5.3	0.007

N.S. non-significant.

Table 4
Multiple comparison of critical shoulder angle and greater tuberosity angle.

Comparison between the groups	p-value of critical shoulder angle	p-value of greater tuberosity angle
Group A vs B	0.002	N.S.
Group A vs C	0.011	0.004
Group A vs D	0.003	0.028
Group A vs E	N.S.	N.S.
Group B vs C	N.S.	N.S.
Group B vs D	N.S.	N.S.
Group B vs E	N.S.	N.S.
Group C vs D	N.S.	N.S.
Group C vs E	N.S.	N.S.
Group D vs E	N.S.	N.S.

N.S. non-significant.

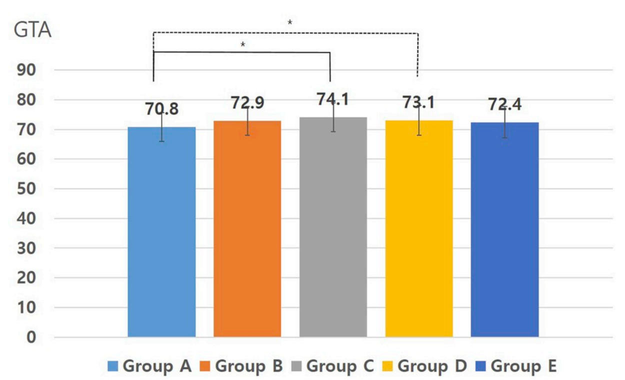

Fig. 5. Comparison of the greater tuberosity angle between groups. Statistically significant differences are indicated by brackets and an asterisk.

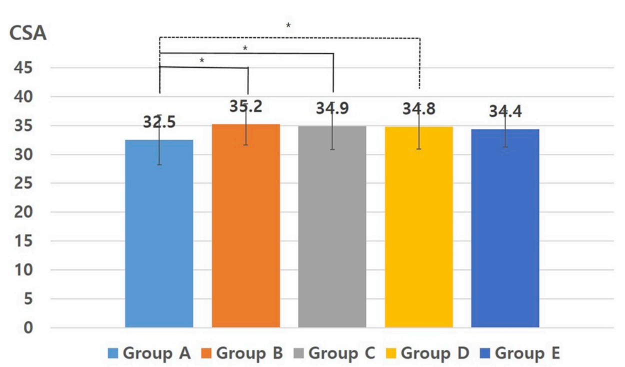

Fig. 6. Comparison of the critical shoulder angle between groups. Statistically significant differences are indicated by brackets and an asterisk.

According to the delaminated patterns, the mean GTA were 70.8° ± 4.9° in Group A, 72.9° ± 4.9° in Group B, 74.1° ± 4.9° in Group C, 73.1° ± 5.0° in Group D, and 72.4° ± 5.3° in Group E (Table 3). The GTA of Group C ($p = 0.004$) and D ($p = 0.028$) was significantly larger than that of control group. (Table 4, Fig. 5).

The mean CSA of control group was 32.6° ± 4.3° and that of RCTs groups (Group B, C, D, and E) was 34.9° ± 3.8°, the CSA of RCTs groups was significantly larger than control group ($p < 0.001$). According to the delaminated patterns, the mean CSA were in Group B, 34.9° ± 4.1° in Group C, 34.8° ± 3.9° in Group D, and 34.4° ± 3.1° in Group E (Table 3). The CSA of Group B ($p = 0.002$), C ($p = 0.011$) and D ($p = 0.003$) were significantly larger than that of control group (Table 4, Fig. 6).

Multivariable analysis also showed that a larger GTAs had a significantly increased risk of group B, C, and D, with the odds ratio of 1.09, 1.15 and 1.079per degree, respectively. However, there was no difference of GTA and CSA according to the delamination patterns. (Table 5).

6. Discussion

This is first study shows relationship between radiologic parameters (GTA and CSA) and delamination patterns of RCTs. Large critical shoulder angle and greater tuberosity angle were associated with rotator cuff tears. However, there was no difference of GTA and CSA according to the delamination patterns.

Tear of rotator cuffs is explained by many mechanisms.[5,12,20,21] One of them is tensile stress overload on rotator cuff tendon.[5,7,20,22] In finite element analyses, articular side of the supraspinatus tendon is on high concentration of the tensile stress.[7,8,22] Sano et al. also showed high stress tensile is concentrated on the articular side of supraspinatus tendon in existence of all 3 types of partial tear.[23] Histologically, Nakajima et al. reported that bursal-side layer composed of bundles of tendon and articular-side as a complex of ligament, joint capsule and tendon. They concluded bursal side layer is more tolerable in a tensile load than articular-side layer.[20] So, the tensile stress on the rotator cuff tendon may be more associated with articular side than bursal side.

In addition, Moor et al. combined two potential risk factors for degenerative tear of rotator cuff (lateral extension of the acromion and inclination of the glenoid) as CSA.[10,24] This radiographic marker is supported by many clinical studies.[25–27] Biomechanical studies verified that overload of high tensile strengths with high CSA might result in RCTs.[11,24] We hypothesized that delaminated tear with articular layer is associated with larger CSA. In the present study, there was no difference of CSA according to the delaminated patterns. Although only bursal layer more medially retracted delaminated tear group did not show significant difference of CSA comparison with the control group, the number of group E was only sixteen, it might have been a source of a type 2 error due to the sample size used.

The CSAs of the groups in our study were different from previous studies. Moor et al. noted RCTs was present in 84% of patients with a CSA > 35°.[5] Pandey et al. reported even higher cutoff values of the CSA as > 39.3° and CSA of FTRCTs as 41.01° ± 3.1.[27] Cabezas et al.[23] recently compared the CSA between East Asian and North American pulations and noted that the CSA was significantly larger in the East Asians than in the North Americans (mean 32.8° ± 4.4° vs., 27.7° ± 4.8° respectively). In 2018, Shinagawa et al.[26] reported that in 295 east Asians, the mean CSA of FTRCTs was 34.3° ± 4.2°, and the control group was 32.3° ± 4.5. And the mean CSAs of each groups are similar with the results of Shinagawa et al. are similar with this study.[26]

Cunningham et al.[18] introduced GTA as a reliable radiographic marker detecting RCTs which is highly predictive with more than 70°. They reported in patients, the mean GTA values were 72.5° ± 2.5° and for control group, 65.2° ± 4.1° ($p < 0.01$). In the present study, the mean GTA of control group was 70.8° ± 4.9°, although the mean GTA

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

Factor	Odd ratios (95% CI)							
	Group B	p- value	Group C	p- value	Group D	p- value	Group E	p- value
Critical shoulder angle	1.18 (1.07–1.30)	0.001	1.14 (1.04–1.25)	0.005	1.15 (1.06–1.24)	0.001	1.11 (0.97–1.27)	0.123
Greater tuberosity angle	1.09 (1.01–1.17)	0.021	1.15 (1.06–1.24)	0.001	1.09 (1.03–1.17)	0.005	1.07 (0.96–1.19)	0.247
Age, per ten years	1.45 (0.96–2.20)	0.077	1.59 (1.04–2.44)	0.032	1.84 (1.25–2.71)	0.002	1.87 (1.06–3.30)	0.030
Sex, female to male	1.48 (0.82–3.60)	0.217	1.76 (1.10–5.26)	0.015	1.26 (1.02–3.87)	0.531	1.96 (1.12–10.81)	0.001
Right arm to left arm	0.48 (0.23–1.02)	0.056	0.78 (0.36–1.66)	0.515	0.48 (0.25–0.93)	0.029	0.33 (0.09–1.27)	0.106
Body mass index	1.07 (0.97–1.18)	0.205	1.01 (0.90–1.14)	0.868	103 (0.93–1.15)	0.550	0.99 (0.82–1.18)	0.887
Non-smoker to smoker	1.15 (0.54–2.47)	0.717	0.43 (0.16–1.14)	0.089	1.05 (0.53–2.09)	0.888	0.90 (0.26–3.18)	0.873

of RCTs (73.2° ± 5.0°) was similar to the report of Cunningham et al.[18] Although the statistical analysis was not performed yet, the authors assumed that because East Asians had smaller humeral head than Europeans, GTA is larger in East Asians than Europeans.

Cunningham et al.[18] presented the exact cause of high GTA in RCT patient remained unclear, whether the vector between supraspinatus muscle and the deltoid muscle is divergent, or the undersurface of the acromion can be impinged by the greater tuberosity. Our findings that between the delaminated patterns, although possibility of type 2 error of group E also should be considered, the mean GTA of the delaminated tears except for bursal layer more medially retracted delaminated tear were larger than that of control group, otherwise the mean GTA of the non-delaminated tear did not showed significant difference with the control group. Biomechanical study is necessary for the accurate evaluation about the influence of GTA.[11]

Our study has several limitations. First, measurement errors could be existed despite the excellent inter-observer agreement. To reduce such errors, measurements were performed independently, and the results were not disclosed to the other surgeon. Second, anteroposterior radiographs were taken in this study. Recent studies cautioned that factors such as patient positioning, gantry and plate positioning, and scapular positioning influenced the reliability of measuring CSA.[20,25] Radiographic standardization as a protocol, 100% accuracy cannot be achieved in various measurements, causing some aberration in technique. This may have led to some bias. Third, 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. Fourth, the patients in the control group were also younger than those in the RCTs groups. Age-matching comparison is necessary to prove the difference in the relationship of the radiologic measurements between the control and RCTs groups because the radiologic measurements can be changed with increasing age. However, comparison between each RCTs groups according to the delamination patterns is possible because there was no difference in the age of the patients. Fifth, the difference of GTA and CSA with and without rotator cuff tears was approximately 3–4°; whereas, the SD was > 3°. Careful interpretation of the results is necessary for determining clinical application of GTA and CSA though it is statistically significant. Finally, other morphologic parameters of an acromion, such as acromial spur or Acromial index were not investigated in this study.[27]

7. Conclusion

Large greater tuberosity angle and critical shoulder angle were associated with rotator cuff tears. However, there was no difference of greater tuberosity angle and critical shoulder angle according to the delamination patterns.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jor.2019.03.015.

References

1. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? *J Bone Joint Surg Am.* 2005;87(6):1229–1240.
2. Flurin PH, Landreau P, Gregory T, et al. [Arthroscopic repair of full-thickness cuff tears: a multicentric retrospective study of 576 cases with anatomical assessment]. *Rev Chir Orthop Reparatrice Appar Mot.* 2005;91(S8):31–42.
3. Sonnabend DH, Watson EM. Structural factors affecting the outcome of rotator cuff repair. *J Shoulder Elbow Surg.* 2002;11(3):212–218.
4. Sonnabend DH, Yu Y, Howlett CR, Harper GD, Walsh WR. Laminated tears of the human rotator cuff: a histologic and immunochemical study. *J Shoulder Elbow Surg.* 2001;10(2):109–115.
5. Seitz AL, McClure PW, Finucane S, Boardman 3rd ND, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clin Biomech.* 2011;26(1):1–12.
6. Hashimoto T, Nobuhara K, Hamada T. Pathologic evidence of degeneration as a primary cause of rotator cuff tear. *Clin Orthop Relat Res.* 2003(415):111–120.
7. Inoue A, Chosa E, Goto K, Tajima N. Nonlinear stress analysis of the supraspinatus tendon using three-dimensional finite element analysis. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(5):1151–1157.
8. Wakabayashi I, Itoi E, Sano H, et al. Mechanical environment of the supraspinatus tendon: a two-dimensional finite element model analysis. *J Shoulder Elbow Surg.* 2003;12(6):612–617.
9. Sano H, Wakabayashi I, Itoi E. Stress distribution in the supraspinatus tendon with partial-thickness tears: an analysis using two-dimensional finite element model. *J Shoulder Elbow Surg.* 2006;15(1):100–105.
10. 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 Lett J.* 2013;95-B(7):935–941.
11. Gerber C, Snedeker JG, Baumgartner D, Viehofer AF. Supraspinatus tendon load during abduction is dependent on the size of the critical shoulder angle: a biomechanical analysis. *J Orthop Res.* 2014;32(7):952–957.
12. Neer 2nd CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am.* 1972;54(1):41–50.
13. Toivonen DA, Tuite MJ, Orwin JF. Acromial structure and tears of the rotator cuff. *J Shoulder Elbow Surg.* 1995;4(5):376–383.
14. Tuite MJ, Toivonen DA, Orwin JF, Wright DH. Acromial angle on radiographs of the shoulder: correlation with the impingement syndrome and rotator cuff tears. *AJR Am J Roentgenol.* 1995;165(3):609–613.
15. Flatow EL, Soslowsky LJ, Ticker JB, et al. Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. *Am J Sports Med.* 1994;22(6):779–788.
16. Schneeberger AG, Nyffeler RW, Gerber C. Structural changes of the rotator cuff caused by experimental subacromial impingement in the rat. *J Shoulder Elbow Surg.* 1998;7(4):375–380.
17. Ogawa K, Yoshida A, Inokuchi W, Naniwa T. Acromial spur: relationship to aging and morphologic changes in the rotator cuff. *J Shoulder Elbow Surg.* 2005;14(6):591–598.
18. Cunningham G, Nicodeme-Paulin E, Smith MM, Holzer N, Cass B, Young AA. The greater tuberosity angle: a new predictor for rotator cuff tear. *J Shoulder Elbow Surg.* 2018;27(8):1415–1421.
19. Choo HJ, Lee SJ, Kim JH, et al. Delaminated tears of the rotator cuff: prevalence, characteristics, and diagnostic accuracy using indirect MR arthrography. *AJR Am J Roentgenol.* 2015;204(2):360–366.
20. Nakajima T, Rokuuma N, Hamada K, Tomatsu T, Fukuda H. Histologic and biomechanical characteristics of the supraspinatus tendon: Reference to rotator cuff tearing. *J Shoulder Elbow Surg.* 1994;3(2):79–87.
21. Fukuda H, Hamada K, Nakajima T, Tomonaga A. Pathology and pathogenesis of the intratendinous tearing of the rotator cuff viewed from en bloc histologic sections. *Clin Orthop Relat Res.* 1994(304):60–67.
22. Luo ZP, Hsu HC, Grabowski JJ, Morrey BF, An KN. Mechanical environment associated with rotator cuff tears. *J Shoulder Elbow Surg.* 1998;7(6):616–620.
23. !!! INVALID CITATION !!.
24. Moor BK, Kuster R, Osterhoff G, et al. Inclination-dependent changes of the critical shoulder angle significantly influence superior glenohumeral joint stability. *Clin Biomech.* 2016;32:268–273.
25. Beeler S, Hasler A, Getzmann J, Weigelt L, Meyer DC, Gerber C. Acromial roof in patients with concentric osteoarthritis and massive rotator cuff tears: multiplanar analysis of 115 computed tomography scans. *J Shoulder Elbow Surg.* 2018;27(10):1866–1876.
26. Shinagawa K, Hatta T, Yamamoto N, et al. Critical shoulder angle in an East Asian population: correlation to the incidence of rotator cuff tear and glenohumeral osteoarthritis. *J Shoulder Elbow Surg.* 2018;27(9):1602–1606.
27. Pandey V, Vijayan D, Tapashetti S, et al. Does scapular morphology affect the integrity of the rotator cuff? *J Shoulder Elbow Surg.* 2016;25(3):413–421.