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Relationship between the morphology of the greater tuberosity and radiological and clinical outcomes after arthroscopic rotator cuff repair

Kenji Kawashima, MD[a,*], Hiroyuki Sugaya, MD[b], Norimasa Takahashi, MD[b], Keisuke Matsuki, MD, PhD[b], Yasutaka Takeuchi, MD[b], Nobuo Terabayashi, MD, PhD[a], Haruhiko Akiyama, MD, PhD[a]

[a] Department of Orthopaedic Surgery, Gifu University Graduate School of Medicine, Gifu, Japan
[b] Funabashi Orthopaedic Sports Medicine & Joint Center, Funabashi, Chiba, Japan

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Background: Degenerative greater tuberosity (GT) changes are often associated with rotator cuff tears. However, little is known about the impact of GT morphology on surgical outcomes. The aim of this study was to examine the relationship between clinical and radiological outcomes, after rotator cuff repair, and GT morphology.

Methods: We retrospectively investigated shoulders that underwent arthroscopic repair of non-traumatic full-thickness supra-/infraspinatus tears. The exclusion criteria were a lack of either radiographs or magnetic resonance images, revision surgery, partial repair, complications such as infection or dislocation, and follow-up < 2 years. GT morphology on radiographs was classified into 5 groups: normal, sclerosis, bone spur, roughness, and femoralization. The acromiohumeral interval (AHI) was measured on anteroposterior radiographs. Fatty degeneration of the cuff muscles was evaluated using the global fatty degeneration index (GFDI). Postoperative cuff integrity was classified using Sugaya's classification at 2 years after surgery. Clinical outcomes were assessed preoperatively and at postoperative 2 years with the Japanese Orthopaedic Association score and the University of California, Los Angeles shoulder rating scale.

Results: The study included 220 shoulders in 212 patients (104 men and 108 women), with a mean age of 66 years (range 43-85). The mean follow-up period was 28 months (range, 24-60 months). Seven shoulders (3.2%) were classified as normal, 65 (29.5%) as sclerosis, 55 (25.0%) as bone spur, 78 (34.5%) as roughness, and 15 (6.8%) as femoralization. The preoperative AHI, in the roughness and femoralization groups, was significantly smaller than that in the sclerosis ($P < .01$) and bone spur groups ($P < .001$). The roughness and femoralization groups had a greater number of large tears ($P = .006$). In the roughness and femoralization groups, mean GFDI was significantly higher than that in the sclerosis group ($P < .001$ for both). Repaired cuff integrity was not different between all groups, respectively. Both Japanese Orthopaedic Association and University of California, Los Angeles scores improved postoperatively from 73.3 to 95.6 points and 18.2 to 34.0 points ($P < .001$ for both), respectively, and there were no significant differences between all groups, respectively.

Conclusion: Roughness or femoralization of the GT was related to larger tears, with smaller AHI and higher GFDI. Repaired cuff integrity and clinical outcomes in shoulders with roughness or femoralization of the GT were not inferior to shoulders with the other types of GT morphologies in this study. Arthroscopic repair can be indicated for shoulders with advanced changes of the GT, if fatty degeneration of the cuff muscles is not severe.

This study has been performed at Funabashi Orthopaedic Sports Medicine & Joint Center.
Ethical approval for this study was obtained from the Funabashi Orthopaedic Hospital Institutional Review Board (no. 2018012).

* Corresponding author: Kenji Kawashima, MD, Department of Orthopaedic Surgery, Gifu University Graduate School of Medicine, 1-1 Yanagido, Gifu City, 501-1194, Gifu, Japan.
E-mail address: kawashimars@gmail.com (K. Kawashima).

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Rotator cuff tears (RCTs) are one of the most common causes of shoulder pain. The pathogenesis of RCTs is multifactorial, including, both, extrinsic and intrinsic mechanisms.[24] Chronic impingement is a well-known extrinsic factor of RCTs.[20] The radiographic degenerative changes of the greater tuberosity (GT) are important signs of impingement syndrome[5] and have been reported to be associated with RCTs.[4,6,11,14,15,22,28] Harrison[11] has classified the radiographic features of degenerative GT lesions as follows: irregularity of the cortical bone, erosion of the humeral head, cystic cavitation, and areas of sclerosis.

Recently, radiographic changes of GT morphology, such as bony spurs and sclerosis, have been reported to be related to the size of RCTs[19] or rotator cuff muscle quality.[3] Other authors have also demonstrated that more degenerative changes of the GT are associated with larger RCTs.[2,16] Tear size[17] and fatty degeneration of the rotator cuff muscles[9,13] are the important factors, related to repaired cuff integrity; preoperative atrophy and fatty degeneration of the cuff muscles predict poor postoperative outcomes.[8] Considering these facts, a question was raised whether we could choose arthroscopic rotator cuff repair for shoulders with advanced GT degenerative changes. It remains unclear whether the GT morphology affects the clinical outcomes after rotator cuff repair. The aim of this study was to examine the relationship between clinical and radiological outcomes after arthroscopic repair of nontraumatic RCTs and the morphologic changes of the GT. We hypothesized that the progressive and degenerative changes of GT morphology would lead to worse clinical and radiological outcomes.

Materials and methods

Patient selection

We retrospectively investigated shoulders that underwent arthroscopic rotator cuff repair for RCTs, between April 2012 and April 2015. Ethical approval for this study was obtained from the Funabashi Orthopedic Hospital Institutional Review Board (no. 2018012). We indicated primary repair for supra-/infraspinatus tears, accompanied by less than Goutallier stage-3 fatty degeneration in at least one of the two muscles.

The inclusion criteria of this study were shoulders (1) with full-thickness supra-/infraspinatus tears that required surgical treatment after at least 2-month conservative treatment, (2) without acute onset due to an evident trauma, and (3) that underwent arthroscopic rotator cuff repair using the suture-bridge technique. The exclusion criteria were as follows: 1) lack of either radiographs or magnetic resonance images (MRIs), 2) revision surgery, 3) irreparable RCTs with partial repair, 4) complications such as infection or dislocation, and 5) follow-up <2 years.

Radiographic evaluation

Standardized anteroposterior radiographs of the shoulder which are part of the routine in patients with shoulder problems were used for evaluation of the GT morphology. The beam was angled 20° craniocaudally and the arm was in zero degrees of abduction and externally rotated to visualize the entirety of the humeral head. The GT morphology was classified into 5 groups as "normal," "sclerosis," "bone spur," "roughness," and "femoralization" (Fig. 1). "Sclerosis" was defined as cortical thickening of the cuff footprint without irregular surface; "bone spur," as a prominent spur in the slope of the superior GT[3,19]; "roughness," as irregularity of the GT surface extending from the humeral head to the lateral humeral cortex without prominent spurs,[12] the cystic change was sometimes found; and "femoralization," as rounding off the GT.[21] Radiographic classification was performed by two experienced shoulder surgeons (K.K and K.M) independently, who were blind to patients' data. The surgeons evaluated the radiographs twice at a week interval, for assessment of intrarater reliability. When they made different decisions, the final classification was determined based on the 2 surgeons' consensus. Acromiohumeral interval (AHI) was also measured (the closest distance between the humeral head and the undersurface of the acromion) on the anteroposterior radiographs in standing position, to evaluate the superior migration of the humeral head.

MRI evaluation

MRI was performed with a 1.5-T system (Intera 1.5T; Philips, Amsterdam, the Netherlands). Preoperative fatty degeneration was evaluated for each muscle using Goutallier classification on oblique sagittal T1-weighted MRIs.[8] The global fatty degeneration index (GFDI), the mean value of the Goutallier stages for subscapularis, supraspinatus, and infraspinatus muscles, was calculated for each

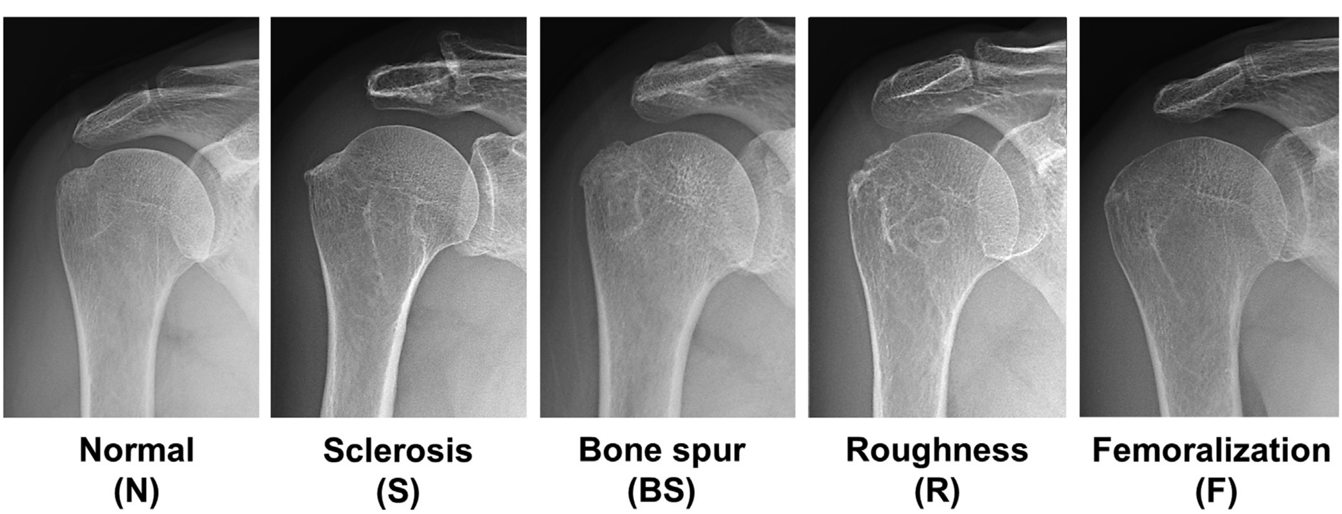

Figure 1 Classification of greater tuberosity morphology. The morphology is classified as "normal (N)," "sclerosis (S)," "bone spur (BS)," "roughness (R)," and "femoralization (F)" on anteroposterior radiographs with shoulder external rotation.

shoulder.[9] Repaired cuff integrity was evaluated using Sugaya's classification on oblique coronal T2-weighted MR images 2 years after surgery, and types IV and V were considered to have a retear.[26] The MRI parameters of the T2 coronal scans were as follows: repetition time 5,000 ms; echo time 100 ms; field of view 160 mm; and matrix 512 × 800. For the T1-weighted oblique sagittal scans, the parameters were repetition time 400 ms; echo time 10.5 ms; field of view 160 mm; and matrix 400 × 720.

Surgical procedure

Surgeries were performed in the beach chair position, under general anesthesia, with an interscalene block by experienced shoulder surgeons (H.S. and N.T.). During arthroscopic surgery, tear size was evaluated as the mediolateral width in accordance with DeOrio and Cofield classification: small, <1 cm; medium, 1-3 cm; large, 3-5 cm; massive, >5 cm.[7] Subacromial decompression was routinely performed. Bony spur or protrusion of the GT was abraded using a burr, and the cuff footprint was decorticated.

Rotator cuff tendons were repaired using the medial knot-tying after suture-bridge lateral-row repair techniques.[13,25,27] One to 3 triple-loaded suture anchors were inserted at the medial border of the footprint in accordance with tear size, and two different sutures were passed through the rotator cuff at a time. Suture-bridge lateral-row fixation was initially performed using 2 of 3 sutures from an anchor. After completion of suture-bridge fixation, the remaining medial-row sutures were tied in a mattress fashion (Fig. 2).

Shoulders were immobilized using an abduction sling for 4 weeks after surgery. Isometric rotator cuff and relaxation exercises of the shoulder girdle muscles were initiated immediately after surgery. Passive and active-assisted range of motion (ROM) exercises were initiated after sling removal, and active ROM and muscle strengthening exercises were initiated 6 weeks after surgery. Light physical activity or exercise were allowed 3 months after surgery, and heavy labor or sports activities were allowed 6 months after surgery, in accordance with each patient's functional recovery.

Patient assessment

Each patient was preoperatively and postoperatively examined by one of our experienced shoulder surgeons (H.S. or N.T.) with active ROM (forward flexion, external rotation at the side, and internal rotation). The shoulder function was also assessed using the Japanese Orthopaedic Association (JOA) score and the University of California, Los Angeles (UCLA) shoulder rating scale. Clinical outcome measures were evaluated preoperatively and postoperatively at 2 years.

Statistical analysis

Statistical differences between the different GT morphologies were analyzed using Kruskal-Wallis one-way analysis of variance on ranks with post hoc Dunn's test. The chi-square test was used to compare categorical variables. Statistical comparisons between preoperative and postoperative clinical scores were conducted using Mann-Whitney U test. The intra- and inter-rater reliability were analyzed using kappa coefficients. All analyses were performed using GraphPad Prism 8.0 software (GraphPad Software, Inc., San Diego, CA, USA), and P values less than .05 were considered to reflect statistically significant differences.

Results

Patients

A total of 621 shoulders (in 609 patients) underwent arthroscopic rotator cuff repair for full-thickness RCTs during the study period (Fig. 3). Among them, 164 shoulders had acute onset with an evident trauma, and there were 457 shoulders with chronic full-thickness rotator cuff tears. Shoulders were excluded if lacking either radiographs or MRI (n = 86), revision shoulder surgery (n = 13), irreparable tears with partial repair (n = 8), and postoperative complications (n = 4). Therefore, the remaining 346 shoulders were candidates for this study; however, 126 shoulders were lost to follow-up. As a result, the subjects of this study consisted of 220 shoulders in 212 patients which is 64% of follow-up rate, including 104 men and 108 women, with a mean age of 66 years (range, 43-85 years). The mean follow-up period was 28 months (range, 24-60 months).

Classification of GT morphology

Seven shoulders (3.2%) were classified as normal, 65 shoulders (29.5%) as sclerosis, 55 shoulders (25.0%) as bone spur, 78 shoulders (34.5%) as roughness, and 15 shoulders (6.8%) as femoralization, respectively. The intrarater reliabilities were 0.84 and 0.86 for the two examiners, and the inter-rater reliability was 0.83. Both intra- and inter-rater reliabilities showed almost perfect agreement. There were no significant differences between the 5 groups with respect to age, sex, affected side, and preoperative ROM (Table I).

Preoperative acromiohumeral interval

The preoperative AHI of the 5 groups are shown in Figure 4. A significant relationship was found between the GT morphology and the AHI ($P < .001$). In accordance with the post hoc comparisons, the mean AHI was significantly smaller in roughness group (8.6 ± 2.3 mm) and femoralization group (6.6 ± 1.7 mm) than in sclerosis group (9.8 ± 1.8 mm) ($P = .003$ and $P < .001$, respectively) and bone spur group (10.1 ± 1.8 mm) ($P < .001$ for both).

Rotator cuff tear size

Rotator cuff tear size in each group is shown in Table II. The number of large and massive tears was 0 shoulders (0%) in the normal group, 14 shoulders (22%) in the sclerosis group, 11 shoulders (20%) in the bone spur group, 47 shoulders (60%) in the roughness group, 13 shoulders (87%) in the femoralization group. Comparing the numbers of small/medium and large/massive tears, there was significant difference between the groups ($P = .006$).

Fatty degeneration of the rotator cuff muscles

Preoperative Goutallier stages[8] are shown in Table III. A significant relationship was found between the GT morphology and GFDI ($P < .001$, Fig. 5). In accordance with the post hoc comparisons, the mean GFDI of roughness group (1.71 ± 0.57) was significantly higher than that of the sclerosis group (1.34 ± 0.41, $P < .001$). The mean GFDI of the femoralization group (1.98 ± 0.39) was significantly higher than that of the sclerosis ($P < .001$) and bone spur groups (1.48 ± 0.46, $P = .01$).

Repaired cuff integrity

Repaired cuff integrity was type I in 101 shoulders, type II in 65 shoulders, type III in 20 shoulders, type IV in 20 shoulders, and type V

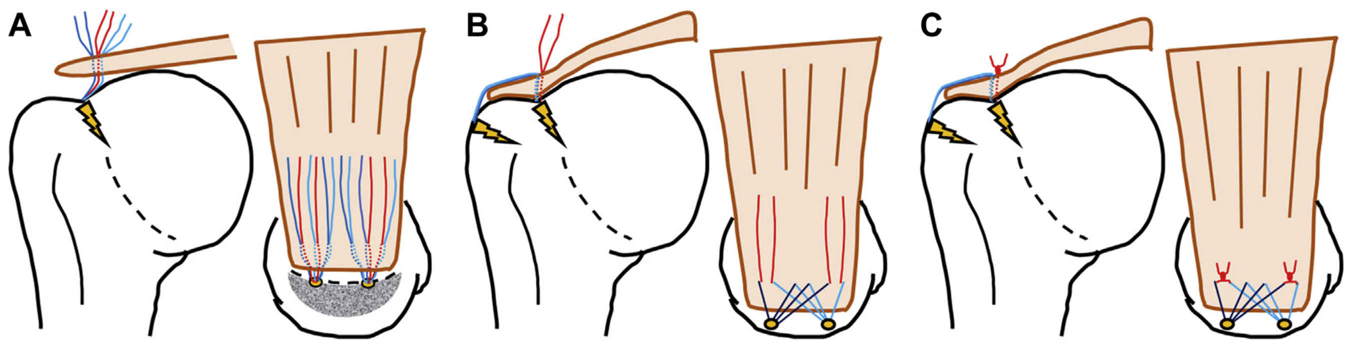

Figure 2 The medial knot-tying after suture-bridge lateral row fixation technique. (**A**) The triple-loaded suture anchors are inserted at the medial border of the footprint, and two different sutures are passed through the rotator cuff at a time. (**B**) Suture-bridge lateral-row fixation is performed initially, using 2 of 3 sutures from an anchor. (**C**) The remaining medial-row sutures are tied in a mattress fashion, to press down the rotator cuff to the footprint.

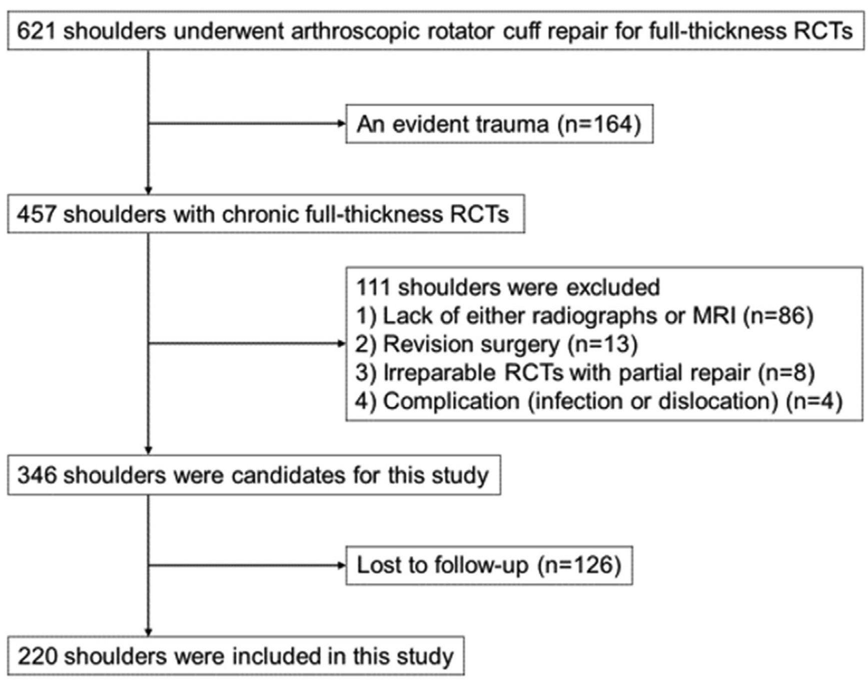

Figure 3 Flowchart for patient selection.

Table I
Demographic data.

Data	Normal	Sclerosis	Bone spur	Roughness	Femoralization	P value
N (%)	7 (3.2)	65 (29.5)	55 (25.0)	78 (34.5)	15 (6.8)	
Age (yr)*	66 ± 6	66 ± 8	67 ± 9	66 ± 8	69 ± 6	.85[†]
Sex (male: female)	3:4	32:33	24:31	41:37	5:10	.65[‡]
Affected side (Right: Left)	7:0	44:21	34:21	61:17	13:2	.056[‡]
Preoperative ROM*						
FF	121 ± 49	144 ± 31	140 ± 32	142 ± 33	144 ± 33	.82[†]
ER	56 ± 14	46 ± 16	45 ± 17	43 ± 17	47 ± 16	.51[†]
IR	T12 ± 3	T12 ± 4	T12 ± 3	T12 ± 3	T10 ± 2	.14[†]

ROM, Range of motion; *FF*, forward flexion; *ER*, external rotation; *IR*, Internal rotation.
[*] Data are presented as means ± standard deviation.
[†] Kruskal-Wallis test.
[‡] Chi-squared test.

in 14 shoulders; the overall retear rate was 15.5% (34 of 220 shoulders). The retear rates of each group were 0% in the normal group, 20% in the sclerosis group, 16% in the bone spur group, 13% in the roughness group, and 13% in the femolarization group (Table IV). The retear rates were not significantly different between the groups.

Clinical outcomes

There were no significant differences in postoperative ROMs between the 5 groups (Table V). The mean JOA score significantly improved from 73 points (range, 48-87 points) to 96 points (range, 72-100 points, $P < .001$). The mean UCLA score also improved from 18 points (range, 7-25 points) to 34 points (range, 23-35 points, $P < .001$). No statistical differences were found between the groups in both preoperative and postoperative JOA scores as well as in UCLA scores.

Discussion

Previous studies have described that the radiographic changes of GT morphology are related to the rotator cuff tear size[2,16,19] and

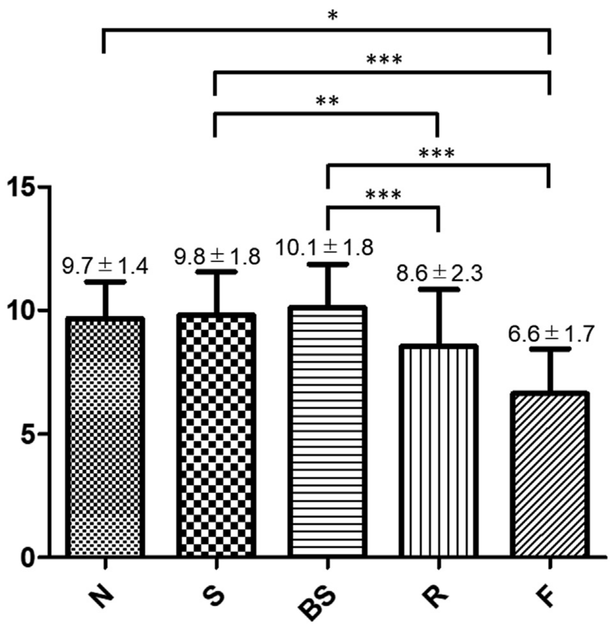

Figure 4 Comparison of the preoperative acromiohumeral interval and the greater tuberosity morphologies. A significant relationship is found between the morphology and acromiohumeral interval (*P* < .001). Data are presented as means ± standard deviation. *N*, normal; *S*, sclerosis; *BS*, bone spur; *R*, roughness; *F*, femoralization. **P* < .05; ***P* < .01; ****P* < .001 with Dunn's multiple comparison test.

Table II
Comparison of rotator cuff tear size.

Tear size*	Normal (n = 7)	Sclerosis (n = 65)	Bone spur (n = 55)	Roughness (n = 78)	Femoralization (n = 15)	P value
Small	4	32	23	4	0	
Medium	3	19	21	27	2	
Large	0	14	11	42	8	
Massive	0	0	0	5	5	
Small and medium	7	51	44	31	2	
Large and massive	0	14	11	47	13	.0056†

* Small, (<1 cm); medium, (1-3 cm); large, (3-5 cm); massive, (>5 cm).
† Chi-squared test.

fatty infiltration or atrophy of the rotator cuff muscles.[3] Choi J-Y et al[2] and Lee SH et al[16] have shown that more degenerative changes of the GT lead to severe RCTs. Chuang et al have also proven that the presence of GT spurs or sclerosis on radiographs predict the occurrence of supraspinatus and infraspinatus muscle atrophy, as well as supraspinatus fatty infiltration.[3]

This study classified the GT morphology into 5 groups: normal, sclerosis, bone spur, roughness, and femoralization, and demonstrated that the roughness and femoralization groups had larger RCTs with smaller AHI and higher GFDI. However, repaired cuff integrity and clinical outcomes were not different between the groups.

The results of this study indicated that the morphologic changes of the GT were associated with rotator cuff tear size and fatty degeneration of the cuff muscles, and that roughness and femoralization in our classification were advanced changes.[10,21] Based on these findings, we speculated on the pathogenesis of the GT morphologic changes that, first, spur or sclerosis are formed by chronic tensile overload and heterogeneous strain from the rotator cuff tendons, as described in literature.[3,5,23] Once a rotator cuff tear

Table III
Comparison of Goutallier stage.

Goutallier stage	Normal (n = 7)	Sclerosis (n = 65)	Bone spur (n = 55)	Roughness (n = 78)	Femoralization (n = 15)
Goutallier (SSC)					
0	0	0	0	1	0
1	6	1	37	38	10
2	0	44	17	25	1
3	0	18	1	13	4
4	1	2	0	1	0
Goutallier (SSP)					
0	0	0	0	0	0
1	6	38	20	23	0
2	1	22	32	48	13
3	0	5	3	7	2
4	0	0	0	0	0
Goutallier (ISP)					
0	0	1	0	2	0
1	7	52	37	36	1
2	0	9	13	28	10
3	0	3	5	12	4
4	0	0	0	0	0

SSC, subscapularis; *SSP*, supraspinatus; *ISP*, infraspinatus.

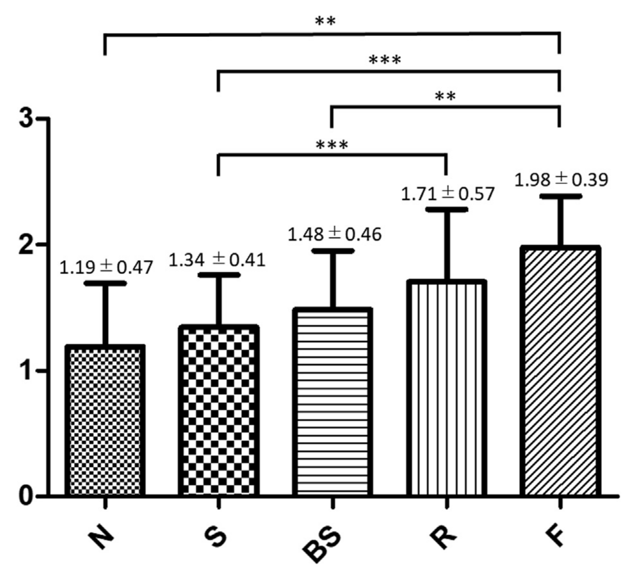

Figure 5 Comparison of the global fatty degeneration index and the greater tuberosity morphologies. Data are presented as means ± standard deviation. *N*, normal; *S*, sclerosis; *BS*, bone spur; *R*, roughness; *F*, femoralization. ***P* < .01; ****P* < .001 with Dunn's multiple comparison test.

occurs, erosion of bone spurs or sclerotic cortex gradually progresses due to subacromial impingement, resulting in cortex surface roughness. Then, persistent contact between the humerus and the acromion leads to rounding off the GT, and finally, femoralization develops.[30]

Against our hypothesis, repaired cuff integrity and clinical outcomes in the femoralization group were comparable with those in the other groups, although larger tears with higher GFDI were predominant. We usually indicated partial repair, superior capsular reconstruction,[18] or reverse shoulder arthroplasty, in accordance with patients' age and shoulder function for irreparable rotator cuff tears with severe fatty degeneration. This study, therefore, did not

Table IV
Comparison of repaired cuff integrity.

Repaired cuff integrity	Normal (n = 7)	Sclerosis (n = 65)	Bone spur (n = 55)	Roughness (n = 78)	Femoralization (n = 15)	P value
Sugaya's classification						
I	2	30	29	33	7	
II	3	17	17	27	1	
III	2	5	0	8	5	
IV	0	9	7	3	1	
V	0	4	2	7	1	
Retear rate, n (%) (Type IV, V)	0 (0)	13 (20)	9 (16)	10 (13)	2 (13)	.59*

* Chi-squared test.

Table V
Comparison of clinical results.

Clinical results	Normal (n = 7)	Sclerosis (n = 65)	Bone spur (n = 55)	Roughness (n = 78)	Femolarization (n = 15)	P value
Postoperative ROM*						
FF	166 ± 8	165 ± 12	162 ± 13	166 ± 9	165 ± 12	.37†
ER	51 ± 14	51 ± 15	48 ± 13	47 ± 14	50 ± 16	.50†
IR	T10 ± 2	T11 ± 3	T10 ± 2	T11 ± 3	T10 ± 2	.26†
Clinical score*						
JOA						
Preop	71 ± 10	73 ± 8	73 ± 9	73 ± 7	78 ± 4	.27†
Postop	96 ± 4	95 ± 5	96 ± 4	95 ± 4	97 ± 2	.76†
UCLA						
Preop	16 ± 4	18 ± 3	19 ± 3	18 ± 3	19 ± 2	.63†
Postop	34 ± 2	34 ± 2	34 ± 2	34 ± 2	34 ± 1	.96†

ROM, Range of motion; *FF*, forward flexion; *ER*, external rotation; *IR*, Internal rotation; *JOA*, Japanese Orthopaedic Association; *UCLA*, University of California at Los Angeles.
* Data are presented as means ± standard deviation.
† Kruskal-Wallis test.

include shoulders with stage-4 supra- and infraspinatus. This may be the reason why the outcomes were good even in the femoralization group. This study indicated that arthroscopic rotator cuff repair could be indicated regardless of the appearance of the GT if MRI showed lesser degrees of fatty degeneration.

This study had several strengths. First, we only studied shoulders with nontraumatic RCTs, while some studies included, both, traumatic and nontraumatic RCTs.[3,15,29] GT morphology may be different between traumatic and nontraumatic RCTs because it has been reported that the acromial morphology in shoulders with degenerative supraspinatus tendon tears differed from that in shoulders with traumatic tears.[1] Second, all RCTs in this study were confirmed during arthroscopic surgery, and the tear size was accurately evaluated. Third, our classification of the GT morphology showed excellent intra- and inter-rater reliabilities. Finally, the sample size of this study was relatively large.

This study also had several limitations. First, this was a retrospective study with short-term follow-up. Second, we included only subjects with shoulders that underwent surgery. Shoulders with only conservative treatment or asymptomatic RCTs might have a different pattern of the GT morphology. Third, irreparable tears or shoulders with severe fatty degeneration of the cuff muscles were not included in this study. This might be the reason for the lack of differences in clinical and radiological outcomes between the groups; however, we demonstrated that we could indicate arthroscopic rotator cuff repair for selected shoulders with advanced GT changes. Finally, we did not consider the time from the onset of a rotator cuff tear to surgery. This period could affect the GT morphology, but it might be difficult to determine when the tear initiated, because this study included nontraumatic chronic tears.

Conclusions

Roughness or femoralization of the GT was related to larger tears with smaller AHI and higher GFDI. Repaired cuff integrity and clinical outcomes in shoulders with roughness or femoralization of the GT were not inferior to shoulders with the other types of GT morphologies in this study. Arthroscopic repair can be indicated for shoulders with advanced changes of the GT, as long as fatty degeneration of the cuff muscles is not severe.

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