JSES International 7 (2023) 561–567

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

The remaining teres minor and subscapularis may contribute to preventing superior migration of the humeral head and progression of osteoarthritic change in rotator cuff tears

Toshifumi Tamura, MD[a], Takuya Tokunaga, MD, PhD[b], Tatsuki Karasugi, MD, PhD[b], Takeshi Miyamoto, MD, PhD[b], Kenshi Kikukawa, MD, PhD[a,*]

[a]Department of Orthopaedic Surgery, Kumamoto General Hospital, Japan Community Healthcare Organization, Yatsushiro, Kumamoto, Japan
[b]Department of Orthopaedic Surgery, Faculty of Life Sciences, Kumamoto University, Kumamoto, Japan

ARTICLE INFO

Keywords:
Rotator cuff tear
Teres minor
Subscapularis
Hypertrophy
Atrophy
Acromiohumeral interval
Remaining cuff

Level of evidence: Anatomy Study; Imaging

Background: Superior migration of the humeral head is common in large and massive rotator cuff tears (RCTs). Humeral heads migrate superiorly according to an increase in the RCT size; however, the relevance of the remaining cuff has not been elucidated. This study investigated the relation between superior migration of the humeral head and the remaining rotator cuff, especially the teres minor (TM) and subscapularis (SSC), in RCTs involving tears and atrophy of the infraspinatus (ISP).
Methods: Plain anteroposterior radiographic and magnetic resonance imaging examinations were performed on 1345 patients between January 2013 and March 2018. A total of 188 shoulders with tears of the supraspinatus and ISP with atrophic ISP were evaluated. Gradings of superior migration of the humeral head and osteoarthritic change were evaluated using the acromiohumeral interval, Oizumi classification, and Hamada classification on plain anteroposterior radiographs. The cross-sectional area of the remaining rotator cuff muscles was evaluated using oblique sagittal magnetic resonance imaging. The TM was classified as hypertrophic (H) and normal and atrophic (NA). The SSC was classified as nonatrophic (N) and atrophic (A). All shoulders were classified as groups A (H-N), B (NA-N), C (H-A), and D (NA-A). Age- and sex-matched patients with no cuff tears were also enrolled (control).
Results: The acromiohumeral intervals of the control group and groups A-D were 11.4 ± 2.4, 9.5 ± 3.8, 7.8 ± 4.1, 7.2 ± 4.0, and 5.4 ± 3.5 mm (84, 74, 64, 21, and 29 shoulders, respectively), with significant differences between groups A and D ($P < .001$) and groups B and D ($P = .016$). Grade 3 of the Oizumi classification and grades 3, 4, and 5 of the Hamada classification were significantly higher in group D than in others ($P < .001$).
Conclusion: The group showing hypertrophic TM and nonatrophic SSC prevented significantly migration of the humeral head and cuff tear osteoarthritis compared to the group showing atrophic TM and SSC in posterosuperior RCTs. The findings indicate that the remaining TM and SSC may prevent superior migration of the humeral head and progression of osteoarthritic change in RCTs. In treating patients with large and massive posterosuperior RCTs, the status of the remaining TM and SSC muscles should be assessed.

Superior migration of the humeral head is often identified in large and massive rotator cuff tears (RCTs). It is recognized as a negative prognostic factor for the clinical evaluation of RCTs,[1] symptomatic RCTs,[5] nonoperative treatment, and arthroscopic débridement for RCTs,[10,20] reparability of RCTs,[9,14,17] and retear rates after rotator cuff repair.[18,21] As superior migration of the humeral head has been used to assess the severity of RCTs, the acromiohumeral interval (AHI) on plain radiographs is measured.[2] A decrease in AHI and glenohumeral and subacromial osteoarthritic changes is regarded as severity indicators radiographically.[2] Several reports have shown that the decrease in AHI was correlated with tear and fatty degeneration of the rotator cuff that involved the infraspinatus (ISP).[5,11,12,19] However, little attention was paid to the remaining cuff, especially the teres minor (TM) and subscapularis (SSC); therefore, the relation between superior migration of the

The ethics committee of Kumamoto General Hospital, Japan Community Healthcare Organization approved this study.

*Corresponding author: Kenshi Kikukawa, MD, PhD, Department of Surgery, Kumamoto General Hospital, Japan Community Healthcare Organization, 10-10 Tohricho, Yatsushiro, Kumamoto 866-8660, Japan.
E-mail address: kikukawakenshi@yahoo.co.jp (K. Kikukawa).

https://doi.org/10.1016/j.jseint.2023.03.005
2666-6383/

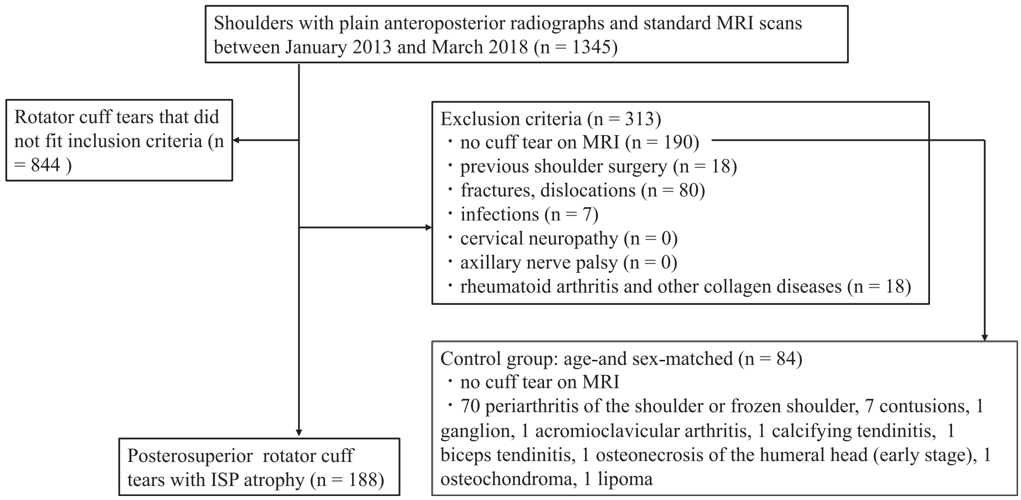

Figure 1 Flow chart summarizing all shoulders in the study. *MRI*, magnetic resonance imaging; *ISP*, infraspinatus.

humeral head and the remaining cuff in RCTs has not been fully elucidated.

Kikukawa et al reported that the TM appeared hypertrophic in RCTs involving ISP on magnetic resonance imaging (MRI), and the progression of ISP atrophy appeared to induce the development of this hypertrophy.[7] Furthermore, shoulders with hypertrophic TM had greater strength and range of external rotation than those with normal or atrophic TM in posterosuperior RCTs. The range of external rotation in shoulders with hypertrophic TM was maintained for the same level as the contralateral asymptomatic side; on the other hand, those in shoulders with normal or atrophic TM significantly decreased.[8] Rhee et al reported that ISP and inferior SSC influenced active anterior elevation in massive RCTs as a result of the measurements of the remaining cuff muscle volumes by MRI.[16] Yoon et al also reported that symptomatic shoulders in patients with irreparable, massive RCTs with intact SSC and hypertrophic TM were more responsive to conservative treatment.[22] They emphasized that the remaining cuff in massive RCTs, especially the TM and the SSC, may contribute to maintaining proper shoulder function. To our knowledge, no reports on the relation between the remaining cuff and superior migration of the humeral head exist.

This study aimed to investigate whether superior migration of the humeral head and severity of cuff tear osteoarthritis on plain radiographs were related to the remaining cuff (TM and SSC) in RCTs on MRI evaluation. We hypothesized that AHI would not decrease in RCTs with hypertrophic TM and nonatrophic SSC and would decrease, showing more severe osteoarthritic changes, in RCTs with atrophic TM and SSC.

Materials and methods

This cross-sectional study was conducted between January 2013 and March 2018 and was approved by the ethical committee of our institution. In total, 1345 patients were evaluated by plain anteroposterior radiographs and MRIs. Shoulders that had full-thickness supraspinatus (SSP) and ISP tears showing atrophic ISP, with or without SSC tears, were included in this study. The exclusion criteria were no cuff tear, previous shoulder surgery, fractures, dislocation, infection, cervical neuropathy, and axillary nerve palsy of the affected shoulder. Patients with rheumatoid arthritis and other collagen diseases were also excluded. Eventually, 188 shoulders were evaluated (Fig. 1).

Radiographic assessment

The radiographic assessment included a conventional anteroposterior radiograph in the standing position with the arm at the side in the neutral arm rotation. The beam was angled 20° craniocaudally and 20° mediolaterally, perpendicular to the plane of the scapula. The grading of superior migration of the humeral head on anteroposterior radiographs based on AHI (Fig. 2*A*), Oizumi classification (Fig. 2*B*),[13] and Hamada classification[2] were evaluated.

MRI evaluation of the ISP, TM, and SSC muscles

MRI examination was performed with a 1.5-T and 3.0-T system (Siemens Corp., Munich, Germany). T2-weighted spin-echo images (2500–5000/120, with a 3-mm section thickness) were obtained. According to the standard findings on the three MRI planes (oblique coronal, oblique sagittal, and axial), all affected shoulders had full-thickness tears of the SSP and ISP tendons with or without SSC tears, which confirmed the discontinuity of the two tendons at the superior and middle facets of the greater tuberosity.[8] We used the MRI evaluation criteria of Kikukawa et al;[7,8] thus, the areas of the ISP, TM, anatomic external rotator (a-ER), and SSC muscles were measured on the most lateral sagittal oblique plane, with the scapular spine in contact with the scapular body (Fig. 3, *A* and *B*). This plane was defined as the most lateral Y-shaped form composed of the spine of the scapula, scapular body, and coracoid process. The 95% confidence interval (CI) of the occupational ratios of the ISP, TM, a-ER, and SSC muscles in the no-cuff tear group were derived in a previous report.[8] The definitions of atrophy and hypertrophy of each muscle were as follows:

Occupational ratio of the ISP muscle = ISP area/a-ER area (95% CI: 0.586–0.810)

Atrophic ISP: Occupational ratio of the ISP <.586

Occupational ratio of the TM muscle = TM area/a-ER area (95% CI: 0.112-0.288)

Atrophic TM: Occupational ratio of the TM < 0.112

Hypertrophic TM: Occupational ratio of the TM > 0.288

Occupational ratio of the SSC muscle = SSC area/a-ER area (95% CI: 0.649-1.282)

Atrophic SSC: Occupational ratio of the SSC <0.649

The affected shoulders were divided into two types according to the TM muscles: hypertrophic TM and normal or atrophic TM, and

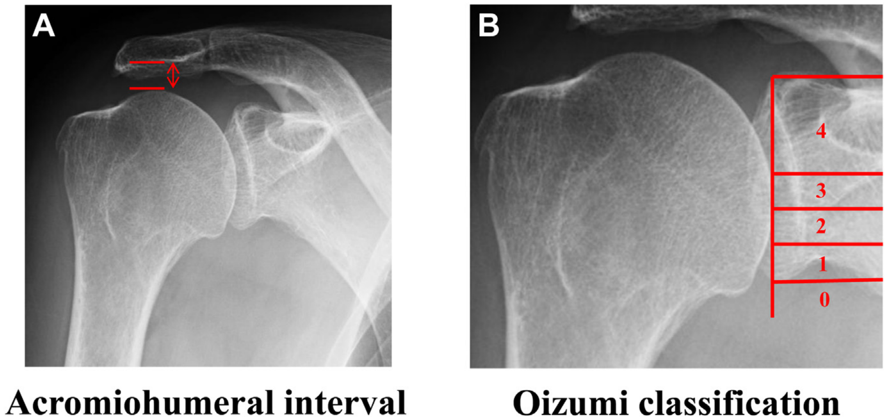

Figure 2 (***A***) The acromiohumeral interval was measured as the smallest distance from the undersurface of the acromion to the superior aspect of the humeral head. (***B***) The grade of superior migration on the Oizumi classification was defined by the inferior border of the glenoid and the humeral head. The inferior half of the glenoid was divided into three zones: in grade 0, the inferior border of the humeral head was equal to or below the lower glenoid; in grades 1, 2, and 3, the inferior border of the humeral head was in each zone. Grade 4 was recognized as the inferior border of the humeral head above zone 3.

into two types according to the SSC muscles: nonatrophic SSC and atrophic SSC. In keeping with these classifications, all affected shoulders were divided into four groups: group A (hypertrophic TM and nonatrophic SSC), group B (normal or atrophic TM and nonatrophic SSC), group C (hypertrophic TM and atrophic SSC), and group D (normal or atrophic TM and atrophic SSC). For comparison with normal shoulders, an age- and sex-matched group of individuals with no cuff tear (control group) was also enrolled (Fig. 1).

A random sample of 120 muscles (ISP, TM, a-ER, and SSC muscles) from 30 individuals was assessed on different occasions by two authors (T.T. and K.K.) to quantify intraobserver and interobserver reliabilities. For intraobserver reliability, each author evaluated all samples twice with two weeks between evaluations.

Statistical analysis

All analyses were performed with the EZR software program (Saitama Medical Center, Jichi Medical University, Saitama, Japan).[4] Differences in the measurements among groups were analyzed using one-way analyses of variance, and post hoc pairwise comparisons were performed using Tukey–Kramer multiple comparison test. Categorical factors were compared using Fisher's exact test, and Bonferroni adjustment was performed for multiple comparisons. Intraobserver and interobserver reliabilities for ISP, TM, a-ER, and SSC areas on MRI scans were evaluated with the intraclass correlation coefficient (ICC) and for the types of ISP, TM, and SSC with Cohen κ statistic.

Results

The participants included 97 men and 91 women, with a mean age of 73.9 ± 8.2 (range, 39-93) years. The demographic data for each shoulder group are summarized in Table I. There were significant differences between groups A and D in age ($P = .023$), with no significant difference between the other groups. No tear of the TM was confirmed on MRI.

The average occupational ratio of the ISP in all affected shoulders was 0.250 ± 0.160 (range, 0-0.585). The ISP muscles were confirmed to be atrophic in all affected shoulders. The occupational ratios of the ISP in groups A, B, C, and D were 0.24 ± 0.15, 0.29 ± 0.17, 0.18 ± 0.14, and 0.22 ± 0.17, respectively (Fig. 4*A*). There was a significant difference between groups B and C ($P = .037$). The occupational ratios of the TM in groups A, B, C, and D were 0.38 ± 0.07, 0.16 ± 0.10, 0.38 ± 0.06, and 0.13 ± 0.10, respectively (Fig. 4*B*). The occupational ratios of the SSC in groups A, B, C, and D were 1.14 ± 0.28, 1.2 ± 0.43, 0.56 ± 0.21, and 0.57 ± 0.18, respectively (Fig. 4*C*). Intraobserver agreements for ISP, TM, a-ER, and SSC muscle measurements were excellent (ICC >0.99), with Cohen κ values of 0.93 (95% CI, 0.80-1.06), 0.84 (95% CI, 0.63-1.05), and 1 (95% CI, 1) for ISP, TM, and SSC, respectively. Interobserver reliability for ISP, TM, a-ER, and SSC muscle measurements were excellent (ICC >0.99), with Cohen κ values of 0.87 (95% CI, 0.69-1.05), 1 (95% CI, 1), and 1 (95% CI, 1) for ISP, TM, and SSC, respectively. Therefore, we concluded that the rates were reliable.

Table I
Demographic data of the shoulders in each group.

Group	Control	A (H-N)	B (NA-N)	C (H-A)	D (NA-A)
Number	84	74	64	21	29
Male:Female	43:41	41:33	37:27	10:11	9:20
Age	72.3 ± 5.4	72.1 ± 8.3	75.3 ± 7.8	72.1 ± 7.5	77.0 ± 7.9

H-N, hypertrophic TM, and nonatrophic SSC; *NA-N*, normal or atrophic TM, and nonatrophic SSC; *H-A*, hypertrophic TM, and atrophic SSC; *NA-A*, normal or atrophic TM, and atrophic SSC; *SSC*, subscapularis; *TM*, teres minor.

The mean AHI of the control group and groups A, B, C, and D were 11.4 ± 2.4, 9.5 ± 3.8, 7.8 ± 4.1, 7.2 ± 4.0, and 5.4 ± 3.5 mm, respectively (Fig. 5). There were significant differences between groups A and D ($P < .001$), groups B and D ($P = .016$), and the control group and all other groups ($P < .001$), with a statistical power of 0.775-1 between the groups with statistical significance.

There were no grade 4 shoulders, assessed according to the Oizumi classification, in any group. There was a significant difference among the groups in the Oizumi classification ($P < .001$), with significant differences between groups A and D ($P < .001$), groups C and D ($P = .045$), and the control group and all other groups ($P < .001$) (Fig. 6). The ratios of grade 3 in groups A, B, C, and D were 8.1%, 14.0%, 4.8%, and 44.8%, respectively, with significant differences between groups A and D ($P < .001$), groups B and D ($P = .029$), groups C and D ($P = .031$), and the control group and groups B ($P = .004$) and D ($P < .001$).

There was a significant difference among the groups in the Hamada classification ($P < .001$), with significant differences between groups A and D ($P < .001$), groups B and D ($P < .001$), and the control group and all other groups ($P < .001$) (Fig. 7). The ratios of grades 3, 4, and 5 in groups A, B, C, and D were 6.8%, 17.2%, 19.0%, and 69.0%, respectively, with significant differences between groups A and D ($P < .001$), groups B and D ($P < .001$), groups C and D

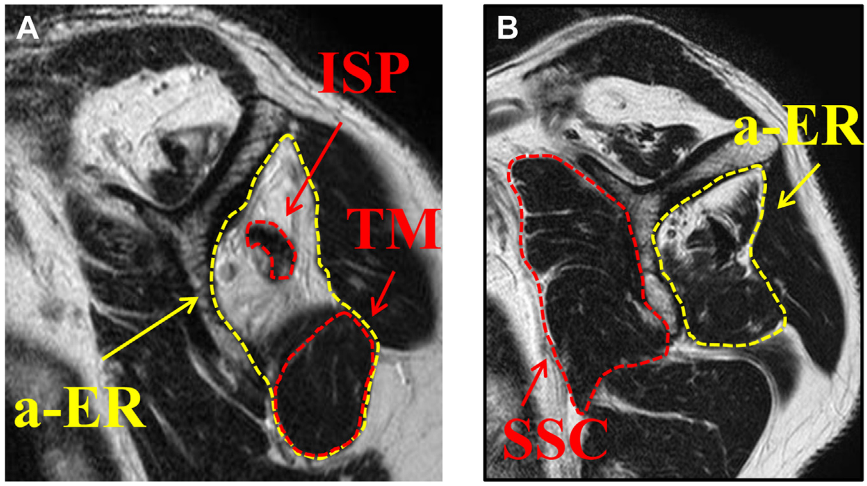

Figure 3 (**A** and **B**) The a-ER muscle was traced on the lateral margin of the scapula, the inferior margin of the TM, and the medial margin of the deltoid. (**A**) The ISP, (**A**) TM, and (**B**) SSC muscles were traced on the margin of each muscle. *a-ER*, anatomic external rotator; *ISP*, infraspinatus; *TM*, teres minor; *SSC*, subscapularis.

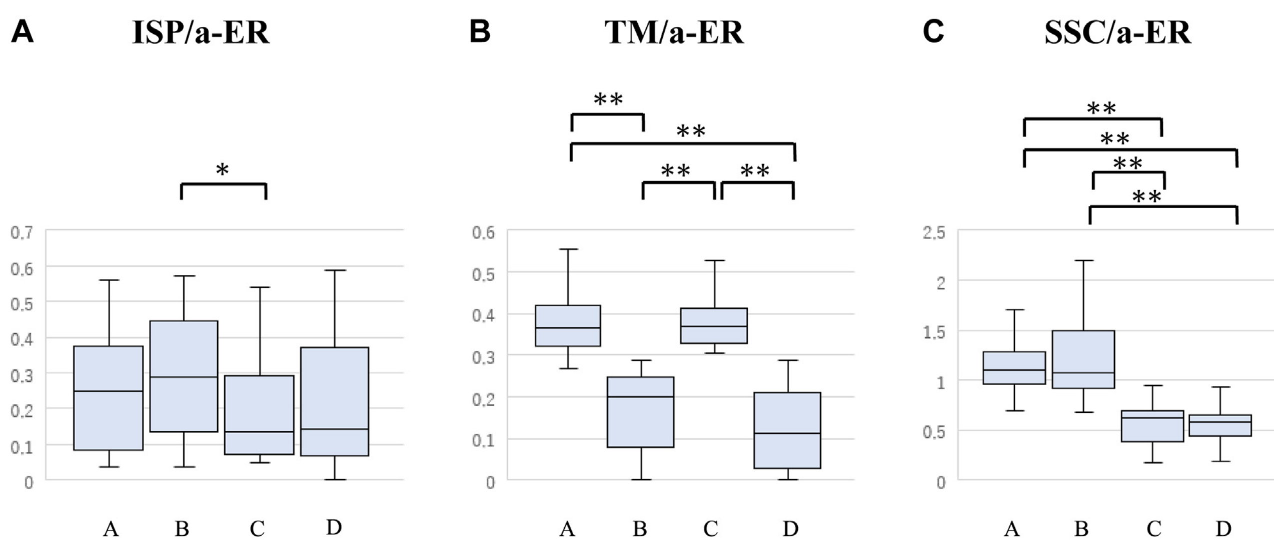

Figure 4 The occupational ratios in each group. *$P < .05$ **$P < .01$. *ISP*, infraspinatus; *TM*, teres minor; *SSC*, subscapularis; *a-ER*, anatomic external rotator.

($P = .006$), and the control group and groups B ($P < .001$), C ($P = .013$), and D ($P < .001$).

Discussion

The present study confirmed the tear and atrophy of the ISP in groups A-D and found that the AHIs in those groups significantly decreased compared to those in the group with no RCTs (control group). Mura et al reported that superior translation of the humeral head significantly increased by cutting the SSP and ISP in a biomechanical study.[11] Nové-Josserand et al reported that the AHI decreased in SSP and ISP tears involving fatty infiltration of the ISP muscle.[12] Additionally, Keener et al reported that humeral heads in SSP and ISP tears migrated more superiorly than those in isolated SSP tears.[5] These reports and our findings indicate that ISP contributes to the suppression of the humeral head as a stabilizer of the shoulder.

Several factors leading to superior migration of the humeral head in RCTs have been reported.[5,11,13,19] These studies have indicated that the humeral head migrated superiorly in accordance with tears of the rotator cuff and progression of atrophy or fatty infiltration of the involved cuff muscles, especially in the SSP and ISP. The present study demonstrated that there were significant differences in the AHI in RCT groups, especially in group D, which remarkably decreased compared with that in other groups (Fig. 5). Furthermore, the ratios of grade 3 Oizumi classification and grades 3, 4, and 5 of the Hamada classification in group D significantly increased compared to those of the other groups (Figs. 6 and 7). These results suggest that superior migration of the humeral head and the severity of cuff tear osteoarthritis may be associated with not only the tear size and severely atrophied or fatty infiltrated rotator cuff muscles but also the status of the remaining TM and SSC.

Kikukawa et al reported that hypertrophic changes of the TM were observed in RCTs involving tear and atrophy of the ISP.[7] They reported that the strength and range of external rotation in hypertrophic TM were maintained in patients with posterosuperior RCTs. In contrast, those in normal and atrophic TM were not. They concluded that hypertrophic change of the TM muscle in RCTs was meant to be compensatory.[8] Yoon et al reported that the failure rate of conservative treatment was low in patients with irreparable, massive RCTs, showing intact SSC and hypertrophic change of the

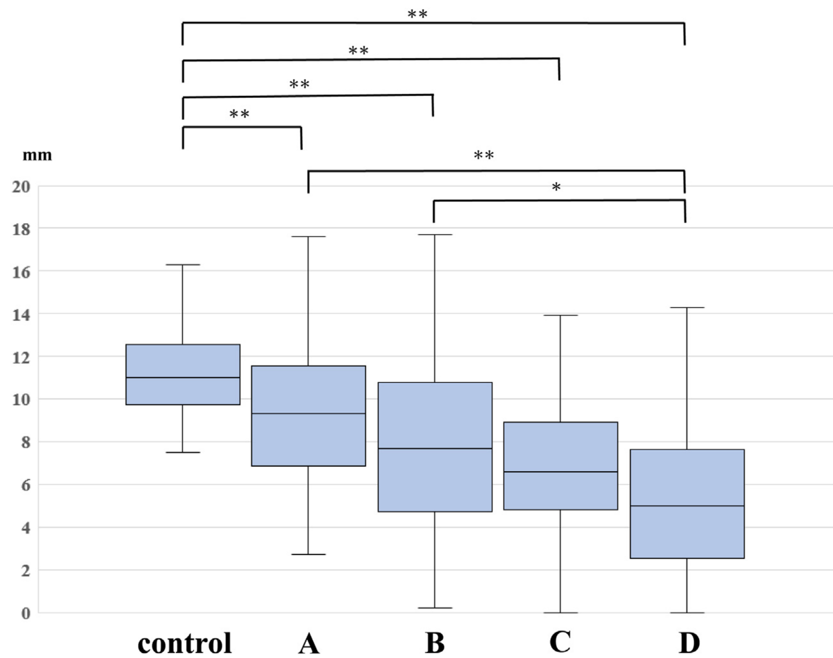

Figure 5 The acromiohumeral interval in each group. *$P < .05$ **$P < .01$.

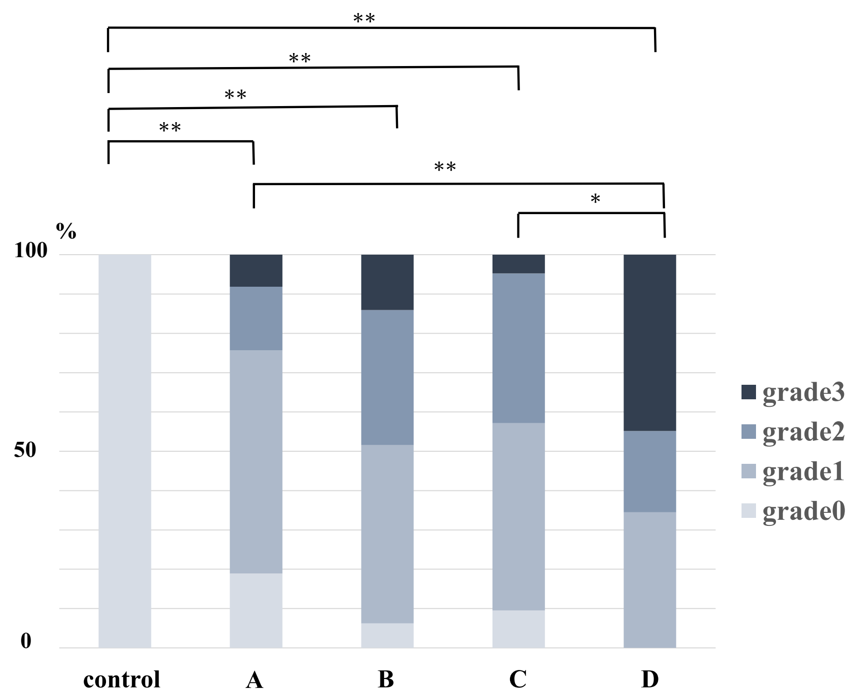

Figure 6 The rate of Oizumi classification grade in each group. *$P < .05$ **$P < .01$.

TM.[22] The present study showed that the mean AHI in group A was 9.5 mm, which did not decrease compared to that in other groups (Fig. 5). Piepers et al reported that there was no significant difference between the muscle volume of the anterior (SSC) and posterior parts (ISP/TM) of the rotator cuff transverse force couple in nonpathologic shoulders.[15] Hypertrophic TM in RCTs indicated a compensatory change to maintain the transverse force couple and prevent the progression of superior migration of the humeral head and cuff tear osteoarthritis, followed by tear and atrophy of the ISP.

Interestingly, the results of the AHI and the grades of Oizumi and Hamada classifications in groups B and C were similar and were between those in groups A and D (Figs. 5–7). These findings prompt the question, “Is the isolated anterior part (nonatrophic SSC) or posterior part (hypertrophic TM) able to prevent the superior migration of the humeral head by itself?” Although we cannot explain the reason correctly due to the study’s cross-sectional nature, we speculate that groups B and C may be on the way to group D.

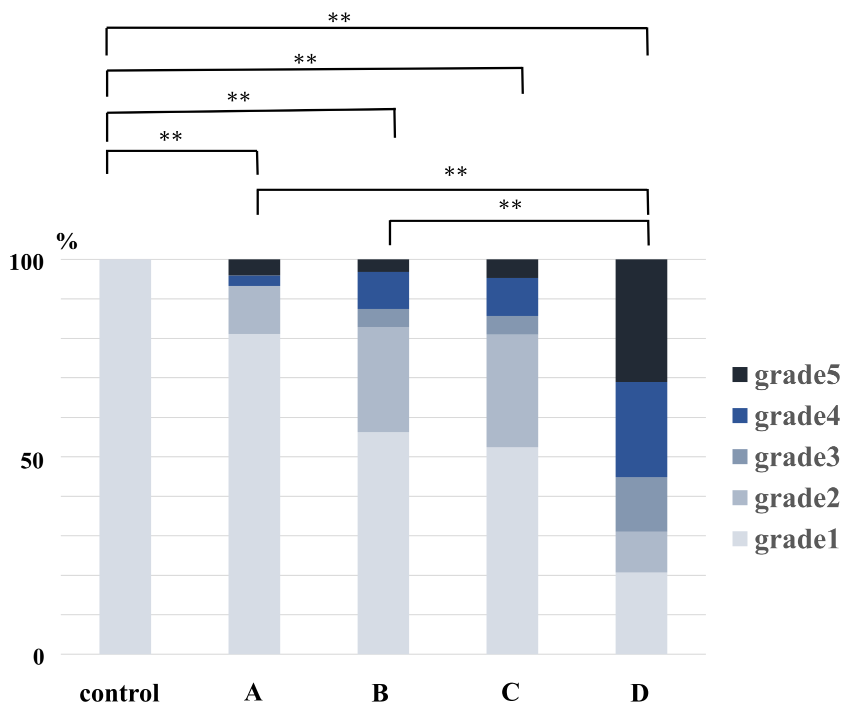

Figure 7 The rate of Hamada classification grade in each group. *$P < .05$ **$P < .01$.

Yoon et al reported that symptomatic shoulders in patients with irreparable, massive RCTs with intact SSC and hypertrophic TM were more responsive to conservative treatment.[22] Rhee et al reported that the ISP and inferior SSC muscle volume loss in massive RCTs showed a significant relationship with the occurrence of pseudoparalysis due to the measurements of the remaining cuff muscle volumes by MRI.[16] The disruption of the transverse force couple was considered to induce the loss of active elevation in RCTs. Considering the above reports, we speculate that the active range and muscle strength of shoulder motion in group D of our classification may have decreased significantly than those in other groups; in contrast, those in group A may have increased. Getting together, it is suggested that a more conservative strategy may be possible in patients with full-thickness RCT without superior migration of the humeral head. While repair should be performed due to altered glenohumeral contact points and an increased risk for accelerated progression to cuff arthropathy.

Appropriate diagnosis and treatment of a massive RCT require the condition to be classified as acute, acute-on-chronic, or chronic. Acute-on-chronic and chronic RCTs usually occur in elderly patients, and outcomes are more unpredictable.[3] The present study included all shoulders with posterosuperior RCTs with ISP atrophy, which are suggested to be probably chronic in all cuff tear groups. Meanwhile, SSC tears may have included some acute tears in addition to acute-on-chronic and chronic tears because the SSC muscles showed atrophic and nonatrophic changes.

The present study had several limitations. First, we did not evaluate anterosuperior RCTs. Second, we did not evaluate the long head of the biceps tendon, which was shown to be a suppressor of the humeral head.[6] Third, no power analysis was performed prior to the present study because it was difficult to set the clinically significant difference between AHI and its standard deviation as the main outcome in the present study. Fourth, only 30 images were evaluated for interrater reliability. Fifth, there was no standardization of plain anteroposterior radiographs, such as the Suter–Henninger classification. Finally, TM was divided into two types in the present study because Kikukawa et al reported the ranges of external rotation were maintained in the hypertrophic TM group; on the other hand, those were significantly decreased in the normal or atrophic TM group.[8] However, we did not evaluate the clinical findings of all shoulders, such as shoulder range and muscle strength. Further studies should be needed.

Conclusions

In total, 188 shoulders with posterosuperior RCTs with or without SSC tears were evaluated for superior migration of the humeral head and osteoarthritic change on plain anteroposterior radiographs and the remaining TM and SSC on MRI. The results demonstrated that the degree of superior migration of the humeral head and severity of cuff tear osteoarthritis were milder in the group with hypertrophic TM and nonatrophic SSC than in the group with atrophic TM and SSC. The remaining TM and SSC may prevent progression to superior migration of the humeral head and osteoarthritic change in RCTs. The relationship between the radiographical assessment of the remaining cuff and clinical shoulder function should be investigated in the future.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Bezer M, Yildirim Y, Akgűn U, Erol B, Gűven O. Superior excursion of the humeral head: a diagnostic tool in rotator cuff tear surgery. J Shoulder Elbow Surg 2005;14:375-9. https://doi.org/10.1016/j.jse.2004.12.001.
2. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res 1990;254:92-6.

3. Jeong JY, Song SY, Yoo JC, Park KM, Lee SM. Comparison of outcomes with arthroscopic repair of acute-on-chronic within 6 months and chronic rotator cuff tears. J Shoulder Elbow Surg 2017;26:648-55. https://doi.org/10.1016/j.jse.2016.09.032.
4. Kanda Y. Investigation of the freely available easy-to-use software "EZR" for medical statistics. Bone Marrow Transpl 2013;48:452-8. https://doi.org/10.1038/bmt.2012.244.
5. Keener JD, Wei AS, Kim HM, Steger-May K, Yamaguchi K. Proximal humeral migration in shoulders with symptomatic and asymptomatic rotator cuff tears. J Bone Joint Surg Am 2009;91:1405-13. https://doi.org/10.2106/JBJS.H.00854.
6. Kido T, Itoi E, Konno N, Sano A, Urayama M, Sato K. The depressor function of biceps on the head of the humerus in shoulders with tears of the rotator cuff. J Bone Joint Surg Br 2000;82:416-9.
7. Kikukawa K, Ide J, Kikuchi K, Morita M, Mizuta H, Ogata H. Hypertrophic changes of the teres minor muscle in rotator cuff tears: quantitative evaluation by magnetic resonance imaging. J Shoulder Elbow Surg 2014;23:1800-5. https://doi.org/10.1016/j.jse.2014.03.014.
8. Kikukawa K, Ide J, Terakawa Y, Takada K, Morita M, Hashimoto K, et al. Hypertrophic teres minor restores shoulder strength and range of external rotation in posterosuperior rotator cuff tears. J Shoulder Elbow Surg 2016;25:1882-8. https://doi.org/10.1016/j.jse.2016.04.016.
9. Kim IB, Jung DW, Suh KT. Prediction of the irreparability of rotator cuff tears. Arthroscopy 2018;34:2076-84. https://doi.org/10.1016/j.arthro.2018.02.033.
10. Klinger HM, Steckel H, Ernstberger T, Baums MH. Arthroscopic debridement of massive rotator cuff tears: negative prognostic factors. Arch Orthop Trauma Surg 2005;125:261-6. https://doi.org/10.1007/s00402-004-0738-6.
11. Mura N, O'Driscoll SW, Zobitz ME, Heers G, Jenkyn TR, Chou SM, et al. The effect of infraspinatus disruption on glenohumeral torque and superior migration of the humeral head: a biomechanical study. J Shoulder Elbow Surg 2003;12:179-84. https://doi.org/10.1067/mse.2003.9.
12. Nové-Josserand L, Edwards TB, O'Connor DP, Walch G. The acromiohumeral and coracohumeral intervals are abnormal in rotator cuff tears with muscular fatty degeneration. Clin Orthop Relat Res 2005;433:90-6. https://doi.org/10.1097/01.blo.0000151441.05180.0e.
13. Oizumi N, Suenaga N, Fukuda K, Minami A. Massive rotator cuff tears repaired on top of humeral head by McLaughlin's procedure. J Shoulder Elbow Surg 2007;16:321-6. https://doi.org/10.1016/j.jse.2006.08.004.
14. Park SH, Choi CH, Yoon HK, Ha JW, Lee C, Chung K. What can the radiological parameters of superior migration of the humeral head tell us about the reparability of massive rotator cuff tears? PLoS One 2020;15:e0231843. https://doi.org/10.1371/journal.pone.0231843.
15. Piepers I, Boudt P, Van Tongel A, De Wilde L. Evaluation of the muscle volumes of the transverse rotator cuff force couple in nonpathologic shoulders. J Shoulder Elbow Surg 2014;23:e158-62. https://doi.org/10.1016/j.jse.2013.09.027.
16. Rhee YG, Cho NS, Song JH, Park JG, Kim TY. Volumetric evaluation of the rotator cuff musculature in massive rotator cuff tears with pseudoparalysis. J Shoulder Elbow Surg 2017;26:1520-6. https://doi.org/10.1016/j.jse.2017.03.017.
17. Shim SB, Jeong JY, Kim JS, Yoo JC. Evaluation of risk factors for irreparable rotator cuff tear in patients older than age 70 including evaluation of radiologic factors of the shoulder. J Shoulder Elbow Surg 2018;27:1932-8. https://doi.org/10.1016/j.jse.2018.07.011.
18. Shin YK, Ryu KN, Park JS, Jin W, Park SY, Yoon YC. Predictive factors of retear in patients with repaired rotator cuff tear on shoulder MRI. AJR Am J Roentgenol 2018;210:134-41. https://doi.org/10.2214/AJR.17.17915.
19. Siow M, Mitchell BC, Hachadorian M, Wang W, Bastrom T, Kent WT, et al. Association between rotator cuff tears and superior migration of the humeral head. An MRI-based anatomic study. Orthop J Sports Med 2021;9. https://doi.org/10.1177/23259671211009846.
20. Vad VB, Warren RF, Altchek DW, O'Brien SJ, Rose HA, Wickiewicz TL. Negative prognostic factors in managing massive rotator cuff tears. Clin J Sport Med 2002;12:151-7. https://doi.org/10.1097/00042752-200205000-00002.
21. Walch G, Maréchal E, Maupas J, Liotard JP. Surgical treatment of rotator cuff rupture. Prognostic factors. Rev Chir Orthop Reparatrice Appar Mot 1992;78:379-88.
22. Yoon TH, Kim SJ, Choi CH, Yoon SP, Chun YM. An intact subscapularis tendon and compensatory teres minor hypertrophy yield lower failure rates for non-operative treatment on irreparable, massive rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2019;27:3240-5. https://doi.org/10.1007/s00167-019-05403-8.