Three-Dimensional Analysis of Acromial Morphologic Characteristics in Patients With and Without Rotator Cuff Tears Using a Reconstructed Computed Tomography Model

Yukitaka Fujisawa, Teruhisa Mihata, Tsuyoshi Murase, Kazuomi Sugamoto and Masashi Neo

Am J Sports Med 2014 42: 2621 originally published online August 12, 2014
DOI: 10.1177/0363546514544683

Three-Dimensional Analysis of Acromial Morphologic Characteristics in Patients With and Without Rotator Cuff Tears Using a Reconstructed Computed Tomography Model

Yukitaka Fujisawa,* MD, Teruhisa Mihata,*† MD, PhD, Tsuyoshi Murase,‡ MD, PhD, Kazuomi Sugamoto,‡ MD, PhD, and Masashi Neo,* MD, PhD
Investigation performed at the Department of Orthopedic Surgery, Osaka Medical College, Takatsuki, Japan

Background: The relationship between rotator cuff tears and acromial shape has yet to be clarified. As a result, the most suitable location for acromioplasty for the treatment of rotator cuff tears is not known.

Purpose: To determine whether any particular change in acromial shape is significantly associated with the presence of rotator cuff tears.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: From 2007 to 2010, we examined 25 consecutive patients with unilateral full-thickness rotator cuff tears who underwent arthroscopic repair and 17 consecutive patients with adhesive capsulitis but intact rotator cuffs who underwent arthroscopic capsular release. Before surgery, a reconstructed 3-dimensional computed tomography model was used to evaluate the acromial structure. Changes in the shape of the affected scapula were qualitatively evaluated relative to the unaffected, contralateral scapula by use of proximity mapping. Differences in acromial structure between affected and unaffected shoulders were assessed at the anterior, lateral, and medial edges and the inferior surface. The association between rotator cuff tear size and change in acromial structure was also evaluated.

Results: Rates of bony projection at the anterior (>2 mm) and lateral (>3 mm) edges of the acromion in patients with rotator cuff tears were significantly greater compared with rates in patients without rotator cuff tears ($P < .01$). Tear size was not correlated with changes in acromial structure (P = .37-.73).

Conclusion: Bone spurs at the anterior and lateral edges of the acromion are associated with the presence of full-thickness rotator cuff tears in symptomatic patients.

Keywords: acromion; morphology; rotator cuff; shoulder; spur; tear

The cause of rotator cuff tears is thought to include both intrinsic factors within the rotator cuff itself and extrinsic factors. In 1934, Codman[5] reported that degenerative changes within the rotator cuff promote tearing of the tendon, and in 1972, Neer[18] suggested that most rotator cuff tears are caused by impingement of proliferative acromial spurs upon the rotator cuff tendons. Recent studies have shown that both intrinsic and extrinsic factors should be evaluated to determine the most suitable treatment for rotator cuff tears.[6,11,17,24,30]

For rotator cuff tears caused by subacromial impingement with acromial spurs, acromioplasty can be performed with or without rotator cuff repair.[4,6,18,21] Since Neer[18] proposed the removal of bone from the anterior and lateral margins of the acromion and removal of the coracoacromial ligament in patients with rotator cuff tears, there has been a substantial increase in the use of acromioplasty.[31] From

†Address correspondence to Teruhisa Mihata, MD, PhD, Department of Orthopedic Surgery, Osaka Medical College, 2-7 Daigaku-machi, Takatsuki, Osaka 569-8686, Japan (e-mails: tmihata@yahoo.co.jp, tmihata@poh.osaka-med.ac.jp).

*Department of Orthopedic Surgery, Osaka Medical College, Takatsuki, Japan.

‡Department of Orthopedic Biomaterial Science, Osaka University, Suita, Japan.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. 42, No. 11
DOI: 10.1177/0363546514544683

1999 to 2008, the mean number of arthroscopic acromioplasties in New York State as reported by Vitale et al[31] increased by 142.3%, compared with only a 13.0% increase in the mean number of total orthopaedic surgery procedures performed. However, it is difficult to compare the clinical results of acromioplasties because surgical techniques differ from surgeon to surgeon. Most surgeons resect the anterior acromion,[4,6,7,16,18] whereas others perform the acromioplasty on the lateral side,[18] medial side,[6] or inferior surface.[6,7,16] To improve clinical results after acromioplasty, the section of the acromion that should be resected for the treatment of rotator cuff tears needs to be determined.

Acromial shape has traditionally been evaluated and classified radiographically[2,6,14,15,19,27,32]; however, results of radiographic evaluations have been inconsistent because of the poor intra- and interobserver agreement of radiographic measurements.[10] Here, we developed a new method of evaluating acromial structure in which reconstructed 3-dimensional computed tomography (CT) models of affected and unaffected scapulae were overlaid and compared. The purpose of this study was to use our new CT evaluation method to determine whether any particular change in acromial structure was significantly associated with the presence of rotator cuff tears. Our hypothesis was that morphologic changes in the acromion associated with rotator cuff tears could be evaluated by use of a reconstructed computed tomography model.

MATERIALS AND METHODS

Inclusion and Exclusion Criteria

Between December 2007 and December 2010, we examined 25 consecutive patients with unilateral full-thickness rotator cuff tears (10 males and 15 females; average age, 61 years; age range, 49-70 years) who underwent arthroscopic repair (torn-RC group), and 17 consecutive patients with adhesive capsulitis but intact rotator cuffs (6 males and 11 females; average age, 57 years; age range, 40-70 years) who underwent arthroscopic capsular release (intact-RC group [control]) (Table 1). There were no significant differences in age and sex between the 2 groups. The presence of intact rotator cuff tendons or the size of the rotator cuff tear in the affected shoulders was evaluated during the scheduled arthroscopic surgery. The presence of an intact rotator cuff in the unaffected, contralateral shoulder was confirmed by use of magnetic resonance imaging, ultrasonography, or both. Rotator cuff tear size was determined with a measuring probe during arthroscopy by the senior author (T.M.) and evaluated by use of the Cofield classification.[6] The rotator cuff tear was small (<1 cm) in 1 patient, medium (1 to <3 cm) in 16 patients, large (3 to <5 cm) in 4 patients, and massive (≥5 cm) in 4 patients. Exclusion criteria were (1) arthroscopically apparent osteoarthritis of the shoulder, (2) a history of shoulder trauma, (3) previous shoulder surgery, or (4) age older than 70 years. All patients signed an informed consent form approved by the institutional review board at our university.

TABLE 1
Patient Demographics[a]

	Torn-RC Group (n = 25)	Intact-RC Group (n = 17)
Age, y, average (range)	61 (49-70)	57 (40-70)
Sex, n		
Male	10	6
Female	15	11
Tear size, n		
Small	1	
Medium	16	
Large	4	
Massive	4	

[a]Intact-RC, patients with adhesive capsulitis and an intact rotator cuff who underwent arthroscopic capsular release; Torn-RC, patients with a unilateral full-thickness rotator cuff tear who underwent arthroscopic repair.

Three-Dimensional Analysis of Acromial Structure

The CT scans of both shoulders of each patient were conducted before arthroscopic shoulder surgery, and the Digital Imaging and Communications in Medicine (DICOM) data from the scans were used. Hitachi (16 detector rows, 1.25-mm-thick slices, 120 kV, 200 mA) and Toshiba (64 detector rows, 1.00-mm-thick slices, 120 kV, 92.5 mA) CT scanners were used for the CT imaging.

We segmented the DICOM data of both scapulae using MV software (Virtual Place-M) (Figure 1) and used the segmented data to generate 3-dimensional bone-surface models that were then saved in VTK file format (Visualization Toolkit; Kitware Inc) (Figure 2). A preliminary study indicated that the average ± SD between the bone-surface model and the actual bone was 0.46 ± 0.03 mm.[22] Next, we generated a mirror-image model of the unaffected scapula using original software (OV; Department of Biomaterials Science, Osaka University) and then superimposed the mirror-image model of the unaffected scapula onto the model of the affected scapula using a technique called surface matching (surface-based registration) and an ICP (iterative closest point) algorithm (Figure 3). Finally, we quantitatively evaluated the morphologic changes in the affected scapula relative to the unaffected scapula using a proximity mapping technique (Figure 4).[9]

For the analysis, the acromial region was divided into 4 areas: anterior edge, lateral edge, medial edge, and inferior surface (Figure 5). The largest difference in acromial structure between the affected and unaffected sides was recorded for each region, and the differences between the torn-RC group and the intact-RC group were compared.

Statistical Analysis

To assess whether acromial shape differed between shoulders with and without rotator cuff tears, we determined cutoff values for each region using receiver operating characteristic (ROC) analysis. We compared each RC tear

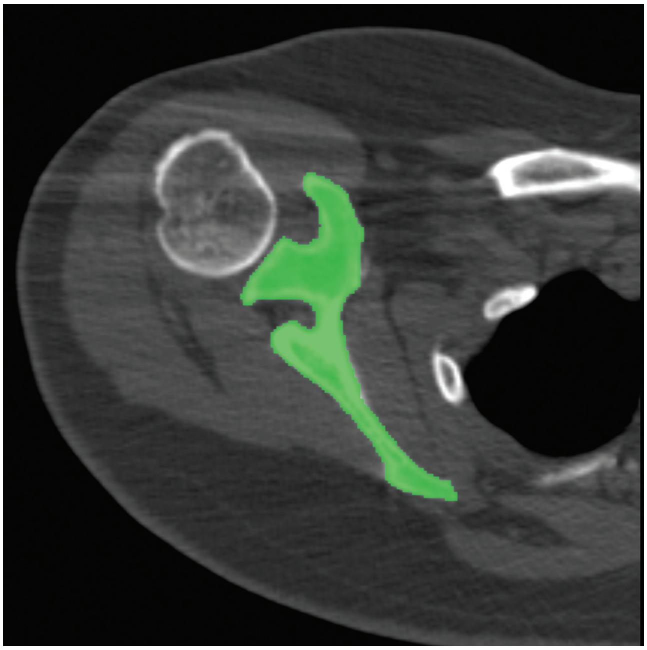

Figure 1. Computed tomography scans of both shoulders were conducted, and the data obtained were segmented by use of MV software (Virtual Place-M, AZE, Japan). Green indicates segmentation of the scapula.

Figure 2. Three-dimensional models of the scapular surfaces were generated from the segmented computed tomography data.

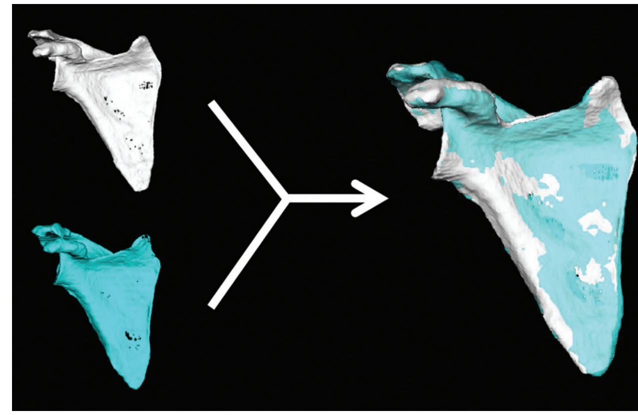

Figure 3. A mirror-image model of the unaffected scapula was created by using original software (OV; Department of Biomaterial Science, Osaka University) and then superimposed onto the model of the affected scapula by using an iterative closest point algorithm. Blue, affected scapula; white, mirror image of unaffected scapula.

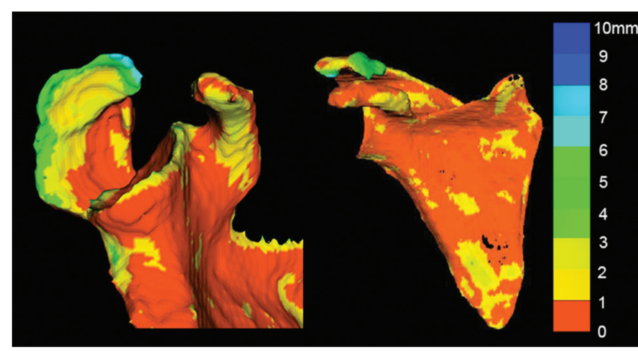

Figure 4. Quantitative evaluation of the morphologic changes in the affected scapula relative to the unaffected scapula in the same patient, as determined by use of a proximity mapping technique. Color was changed based on the side-to-side difference in scapula structure.

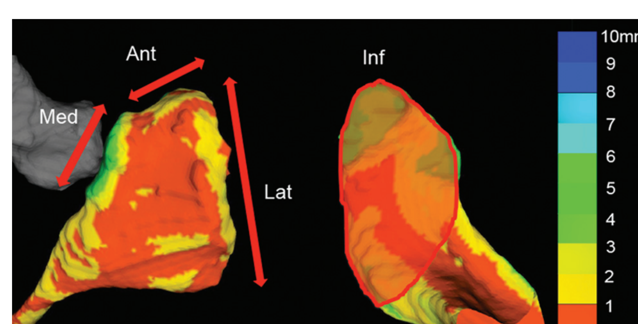

Figure 5. Differences in acromial structure between unaffected and affected shoulders were investigated in 4 regions: anterior edge (Ant), lateral edge (Lat), medial edge (Med), and inferior surface (Inf). The largest difference between the affected and unaffected sides was recorded for each region.

TABLE 2
Maximum Difference in Acromial Structure in Affected Scapulae With and Without Rotator Cuff Tear (No. of Shoulders)[a]

	Anterior Edge		Lateral Edge		Inferior Surface		Medial Edge	
Change in Acromial Shape, mm	Torn-RC Group	Intact-RC Group	Torn-RC Group	Intact-RC Group	Torn-RC Group	Intact-RC Group	Torn-RC Group	Intact-RC Group
≤1	6	3	8	6	10	3	11	5
1 to ≤2	2	10	4	4	4	9	4	5
2 to ≤3	6	3	2	6	4	3	4	2
3 to ≤4	3	1	5	1	4	2	4	5
4 to ≤5	5	0	6	0	3	0	1	0
5 to ≤6	0	0	0	0	0	0	0	0
6 to ≤7	2	0	0	0	0	0	1	0
7 to ≤8	0	0	0	0	0	0	0	0
8 to ≤9	0	0	0	0	0	0	0	0
9 to ≤10	0	0	0	0	0	0	0	0
>10	1	0	0	0	0	0	0	0

[a]The lines indicate cutoff values as determined by receiver operating characteristic analysis. Ant, anterior edge; Inf, inferior surface; Intact-RC, patients with adhesive capsulitis and an intact rotator cuff who underwent arthroscopic capsular release; Lat, lateral edge; Med, medial edge; Torn-RC, patients with a unilateral full-thickness rotator cuff tear who underwent arthroscopic repair.

or adhesive capsulitis shoulder with its contralateral partner and then compared the side-to-side differences in spur size between the 2 groups using the Pearson chi-square test. *P* values <.05 were considered to be statistically significant. Associations between rotator cuff tear size and change in acromial shape were evaluated by use of Pearson correlation analysis.

To evaluate the intra- and interobserver agreement of the 3-dimensional evaluation, 2 experienced shoulder surgeons measured the morphologic changes in the affected scapula relative to the unaffected scapula twice in each subject in the 2 groups. Intraclass correlation coefficients (ICCs) and mean differences were then calculated. All analyses were performed with the JMP9 software package (SAS Institute).

To determine the appropriate sample size, a power analysis was performed with the G*Power3 statistical analysis software package. Effect size (ω) was calculated by defining the sample size as 42, the level of significance (α) as 0.05, and the power ($1 - \beta$) as 0.8.

RESULTS

The power analysis indicated that a total sample size of 42 patients would provide 80% power ($1 - \beta = 0.8$; $\alpha = 0.05$) to detect significant differences in acromial structure, assuming an effect size (ω) of 0.43 (moderate effect).

Changes in Acromial Structure Related to Rotator Cuff Tear

The cutoff values determined by ROC analysis were 2 mm for the anterior edge (torn-RC group, 17/25; intact-RC group, 4/17), 3 mm for the lateral edge (torn-RC group, 11/25; intact-RC group, 1/17), 4 mm for the medial edge (torn-RC group, 2/25; intact-RC group, 0/17), and 4 mm for the inferior surface (torn-RC group, 3/25; intact-RC group, 0/17) (Table 2). Rates of bony projection at the anterior (*P* = .0005) and lateral (*P* = .007) edges of the acromion in the torn-RC group were significantly greater than rates in the intact-RC group. Changes in the inferior surface (*P* = .14) and medial edge (*P* = .23) were not significantly different between the torn-RC and intact-RC groups.

Correlation Between Rotator Cuff Tear Size and Change in Acromial Structure

Rotator cuff tear size was not correlated with change in acromial structure (anterior edge, *P* = .73; lateral edge, *P* = .40; inferior surface, *P* = .52; medial edge, *P* = .37).

Intraobserver and Interobserver Agreement

Intraobserver agreement of the 3-dimensional evaluation of acromial structure entailed ICCs of 0.97 and 0.92, respectively, for each shoulder surgeon in the torn-RC group, and 0.99 and 0.97, respectively, in the intact-RC group. The mean difference in the measurement of acromial structure between the surgeons' first evaluation and second evaluation was 0.62 ± 0.09 mm (mean ± SD) in the torn-RC group for both surgeons and 0.55 ± 0.10 mm and 0.56 ± 0.11 mm in the intact-RC group.

Interobserver agreement for the 3-dimensional evaluation of the acromial structure consisted of ICCs of 0.92 and 0.98, respectively, for each shoulder surgeon, and mean differences of 0.62 ± 0.09 mm and 0.55 ± 0.10 mm in the torn-RC group and the intact-RC group, respectively.

DISCUSSION

Since Neer[18] proposed in 1972 that rotator cuff tears are caused by impingement of proliferative acromial spurs upon the rotator cuff tendons, several authors have investigated the structure of the acromion in patients with rotator cuff disease.[1,23,28,29] However, the relationship between acromial structure and rotator cuff tears remains to be fully established. One of the major reasons for this is the poor intra- and interobserver agreement of radiographic measurements,[10] which are traditionally used to evaluate acromial structure. Here, we developed a new method of evaluating acromial structure in which reconstructed 3-dimensional CT models of the affected scapula and unaffected contralateral scapula are overlaid and compared. We found high intraobserver (ICC, 0.92-0.99) and interobserver (ICC, 0.92-0.98) agreement with this 3-dimensional comparison of scapula structure.

The 3-dimensional analysis of the acromial structure with proximity mapping showed that morphologic changes exceeding 2 mm anteriorly and 3 mm laterally to the acromion were associated with the presence of a full-thickness rotator cuff tear in symptomatic patients, indicating that morphologic changes at the anterior and lateral edges of the acromion are associated with the presence of full-thickness rotator cuff tears. Spurs at the anterior edge of the acromion were noted along the coracoacromial ligament, suggesting that anterior spurs are an enthesopathic change in the coracoacromial ligament, as previously reported.[3,4] Spurs at the lateral edge of the acromion were formed along the deltoid insertion; therefore, they may be a result of mechanical stimulation caused by impingement of the greater tuberosity upon the middle deltoid.

Changes in the inferior surface and at the medial edge of the acromion were not significantly different between the torn-RC group and the intact-RC group, although some patients had more than a 4-mm difference between the affected and unaffected side. This suggests that acromial structure at the inferior surface and at the medial edge is affected by other factors, such as aging, manual work, sports, or abnormality within the acromioclavicular joint.

Rotator cuff tear size was not correlated with the degree of change in acromial structure. Even in small tears of the supraspinatus tendon, large acromial spurs were found in this study. Tear size of the rotator cuff is correlated strongly with the degree of superior humeral head migration,[12] resulting in increased subacromial contact pressure. Therefore, the magnitude of subacromial pressure may not affect the size of acromial spurs. Ogawa et al[20] reported that acromial spur size increases with advancing age. Therefore, the size of acromial spurs may increase with long-term repetitive stress in the subacromial space, even at low pressures.

Neer[18] and others suggest that proliferative acromial spurs reduce the subacromial space and consequently increase the risk of rotator cuff tears.[1,23,28,29] Conversely, other researchers suggest that the shape of the acromion is the result of rotator cuff tears.[25,27,32] Here, we compared the acromial structures of affected and unaffected shoulders. In the intact-RC group, 4 of 17 shoulders had morphologic changes exceeding 2 mm anteriorly, indicating that proliferative acromial spurs may exist in shoulders without rotator cuff tears. However, the positive rate of morphologic changes exceeding 2 mm anteriorly and 3 mm laterally to the acromion in the torn-RC group was significantly higher than that in the intact-RC group, although we excluded any factor that affects acromial structure, including age,[19,32] sex,[8] osteoarthritis of the shoulder, a history of shoulder trauma, and previous shoulder surgery. This suggests that acromial structure may change as a result of rotator cuff tears. Therefore, the acromial spurs can be either the cause or the result of rotator cuff tears.

The population-based incidence of acromioplasties has increased substantially in recent years in the United States.[31] In 2006, there were 19,743 acromioplasties conducted, representing a population incidence of 101.9 acromioplasties per 100,000 population. However, the role of acromioplasty for the treatment of rotator cuff tears remains controversial. In a prospective, multicenter, randomized controlled study, MacDonald et al[13] compared rates of revision surgery in arthroscopic rotator cuff repair with and without acromioplasty; a higher reoperation rate was found in the group that did not undergo acromioplasty. In contrast, some clinical studies have reported no difference in functional outcome for patients who had rotator cuff repair with or without acromioplasty.[16,26] The controversial results may be attributed to different surgical techniques used for acromioplasty. In our study, the presence of acromial spurs at the anterior and lateral edges was significant in the torn-RC group. Therefore, acromioplasty to remove bone from the anterior and lateral margins of the acromion may be useful to correct acromial structure.

Our study has several limitations. First, adhesive capsulitis patients with intact rotator cuffs served as the control group, rather than asymptomatic volunteers with intact rotator cuffs. However, we believe that the presence of shoulder stiffness does not affect the study results because there were no significant differences in age or sex between the 2 groups and we arthroscopically confirmed that the rotator cuffs were intact in the control group subjects. Second, 2 different types of CT scanners were used in the study. However, because the scanners provided CT images of comparable quality, the use of 2 different CT scanners should not have introduced any bias into the study. Third, the sample size may have been insufficient to accurately assess changes in the inferior surface and medial edge of the acromion. The power analysis indicated that 785 patients would be necessary for accurate assessment; however, this number of cases would be difficult to accumulate. Fourth, a cross-sectional study design such as this can only demonstrate association, not cause and effect.

CONCLUSION

Bone spurs at the anterior and lateral edges of the acromion are associated with the presence of full-thickness rotator cuff tears in symptomatic patients. Rotator cuff tear size was not correlated with the degree of change in acromial structure.

ACKNOWLEDGMENT

The authors thank Yasuichiro Nishimura, PhD, for helping with statistical analysis.

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