What Is the Appropriate Reference for Evaluating the Recovery of Supraspinatus Muscle Atrophy After Arthroscopic Rotator Cuff Repair?

The Occupation Ratio of the Supraspinatus May Change After Rotator Cuff Repair Without Volumetric Improvement

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Background: Supraspinatus muscle atrophy is typically assessed by the occupation ratio of the cross-sectional area of the muscle belly to the supraspinatus fossa at the medial border of the coracoid process in a slice along the oblique-sagittal plane on MRI. Previous studies have shown that the occupation ratio of the supraspinatus changed soon after rotator cuff repair compared with before surgery. However, no studies have examined the perioperative change in the muscle volume assessed with 3-dimensional measurement.

Purpose: To compare the volume of the supraspinatus muscle before and soon after surgery by using 3-dimensional imaging and to elucidate whether the changes in the occupation ratio represent corresponding changes in the muscle volume.

Study Design: Cohort study; Level of evidence, 3.

Methods: Thirty shoulders of patients who underwent arthroscopic rotator cuff repair were evaluated. T2-weighted images were obtained before surgery and 2 weeks after surgery. After the muscle and its tendon borders were plotted, the supraspinatus and its tendon were segmented with interactive thresholding in all slices. The 3-dimensional images were then reconstructed and the volumes calculated. Changes in the muscle volume and the occupation ratio were evaluated via 3-dimensional and 2-dimensional image assessments. The 3-dimensional and 2-dimensional findings before and after surgery were compared by use of paired t tests.

Results: The mean muscle volume did not change significantly at a time point soon after surgery in any group. In patients with little medial retraction (n = 7) or isolated detachment at the superior facet (n = 17), no significant differences were noted in the occupation ratio after surgery compared with before surgery. In contrast, in patients with moderate medial retraction (n = 23) or extended tearing in the transverse direction (n = 13), the occupation ratio increased significantly.

Conclusion: Although the muscle volume did not change soon after surgery compared with the preoperative values, in patients with moderate medial retraction or extended tearing in the transverse direction, the occupation ratio increased, probably due to lateral traction of the supraspinatus muscle. We recommend that MRI findings obtained soon after surgery be used as the time-zero reference for evaluating the postoperative changes in the supraspinatus.

Keywords: supraspinatus; rotator cuff repair; occupation ratio; muscle volume; 3-dimensional imaging

When rotator cuff repair is planned, an assessment of muscle atrophy is helpful for predicting the prognosis.2,3 Supraspinatus muscle atrophy is typically assessed by the occupation ratio of the cross-sectional area of the muscle belly to the supraspinatus fossa at the medial border of the coracoid process in a slice along the oblique-sagittal plane on magnetic resonance imaging (MRI).15 However, the occupation area of the supraspinatus (SSP) muscle can increase without recovery of atrophy because of structural changes caused by the operation.6,8,12
occupation ratio can increase soon after surgery even though the muscle volume is unchanged.

To confirm whether the extent of atrophy has changed, the muscle volume before surgery and soon after surgery may need to be compared using the same protocol in 2 consecutive examinations. However, no studies have yet conducted such a comparison.

In the present study, we compared the volume of the SSP muscle before and soon after surgery using 3-dimensional (3D) imaging with the same protocol in 2 consecutive examinations to determine whether the changes in the occupation ratio represented corresponding changes in the muscle volume. The primary endpoint was the change in the muscle volume between the preoperative and postoperative values in all cases. The secondary endpoint was differences in the changes in the occupation ratio and in the volume of the SSP by the degree of medial retraction and by the extent of tearing in the transverse direction.

METHODS

This study was approved by the institutional review board at our institute.

Subjects

A power analysis based on the results of our previous study showed that 20 cases were needed to achieve an α error probability of .05 and a 1-β error probability (power) of .95 for evaluating the differences in the occupation ratios. In the current study, we evaluated 30 shoulders of 30 consecutive patients who underwent arthroscopic rotator cuff repair (ARCR) under the diagnosis of primary rotator cuff tear and who had an MRI examination before and 2 weeks after surgery under the same protocol at our hospital from December 2014 to April 2016. On average, the preoperative MRI scan was performed within 4 weeks (range, 0-14 weeks) before surgery. The exclusion criteria were a history of another traumatic injury, generalized disorder that impaired the joints, central or peripheral compression (bursectomy and acromioplasty in patients with subacromial spur), detachment of adhesion of the rotator cuff to the surrounding tissue, and subscapularis tear, and patients undergoing ARCR with patch graft, latissimus dorsi transfer, or any other procedure to the shoulder.

For evaluation of the secondary endpoint, subjects were divided into 2 groups according to the degree of medial retraction of the SSP in the coronal plane on the preoperative MRI scan and the extent of tearing in the transverse direction in the sagittal plane on the preoperative MRI scan.

According to the Patte classification, medial retraction was assessed by the position of the torn end of the SSP relative to the glenohumeral joint. If the proximal stump of the SSP showed little retraction (Patte stage 1, n = 7), the patients were classified as group 1. In the same manner, if the proximal stump of the SSP lay at the level of the humeral head (stage 2, n = 20) or at the level of the glenoid (stage 3, n = 3), the patients were classified as group 2 (moderate or more retraction).

The extent of tearing in the transverse direction was assessed in the most lateral slice involving the humerus along the oblique-sagittal plane on MRI. According to the Habermeyer classification, the topography of the rotator cuff tear was determined based on the degree of detachment from the greater tuberosity. The degree of tendon detachment was defined by the number of affected facets. Three facets are located on the greater tuberosity (superior, middle, and inferior), and they were easy to define in the most lateral slice of the humerus along the oblique-sagittal image. If tendon detachment was recognized only at the superior facet (SF), the patients were classified as group S (n = 17). If the detachment was recognized at the middle facet (MF) in addition to the SF, the patients were classified as group M (n = 13). Only the SSP muscle was evaluated in this study because the tear of the SSP tendon was the common lesion affected in all patients.

The degree of medial retraction of the SSP and the extent of tearing were identified arthroscopically during surgery. In this series, the degree of medial retraction of the SSP and the extent of tearing obtained from arthroscopy agreed with those noted on preoperative MRI findings.

None of the 30 enrolled participants met the exclusion criteria. Seven participants were assigned to group 1 and 23 to group 2 with the assessment in the coronal plane, and 17 were assigned to group S and 13 to group M with the assessment in the sagittal plane. The inferior facet was not affected in any of the participants (Table 1).

Surgical Technique

Synovectomy in the glenohumeral joint, subacromial decompression (bursectomy and acromioplasty in patients with subacromial spur), detachment of adhesion of the rotator cuff to the surrounding tissue, and subscapularis repair (in patients with subscapularis detachment) were performed before the SSP or infraspinatus (ISP) repair. Single-row repair was performed in patients with a small tear, and double-row repair or suture-bridge repair was performed in patients with medium-sized or larger tears; in cases in which the stump could not be pulled up to the footprint, even after mobilization of the tissue, the repair site was medialized by 5 to 10 mm (n = 13).

MRI

MRI examinations were performed by use of the Signa HDx 1.5-T system (GE Healthcare) and a 3-element

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Imaging Analyses

All data were loaded into an image analysis software program (Mimics Research 15.0; Materialise). Mimics is a reliable image analysis program that enables the operator to segment the range of interest with interactive thresholding.18 This program automatically discerns areas with different pixel values. After several points are plotted on the muscle and tendon borders manually, the software program automatically connects those points while segmenting the muscle and tendon borders. The occupation ratio of the SSP was then calculated with the following formula:

\[
\text{Occupation ratio (\%)} = \left(\frac{\text{cross-sectional area of the SSP}}{\text{cross-sectional area of the SSP fossa}}\right) \times 100.
\]

3D Muscle Volume Evaluation

The 3D images were automatically reconstructed (Figure 4), and the volumes were automatically calculated by integrating the cross-sectional area of the muscle and tendon in each image.

Reliability of the Measurement

Before the main analysis was conducted, the reliability of this method was confirmed. The right shoulders of 10 healthy male volunteers were evaluated. No cuff or muscle lesions were noted in their MRI findings. Two shoulder surgeons performed the 2-dimensional (2D) and 3D measurements, and 1 of these surgeons performed another set of measurements 10 days after the initial measurements. We then analyzed the intra- and interobserver reliability based on the intraclass correlation coefficients (ICCs). Although the cutoff ICC value for reliability remains controversial, the closer this ratio is to 1.0, the higher the reliability17; many studies have reported that an ICC value higher than 0.75 indicates both a strong correlation and reliability.1,8,14

Statistical Analyses

All of the values in the occupation ratio and muscle volume measured before and after surgery showed normal distributions. The occupation ratio and muscle volume measured
after surgery were compared with the preoperative values using a paired t test in each group. All statistical analyses were conducted by use of the SPSS software program, version 23 (IBM Japan). P values less than .05 were considered to be statistically significant.

RESULTS

Reliability

The ICC values for the intra- and interobserver reliability in the 2D evaluation were 0.983 and 0.978, respectively. The ICC values for the intra- and interobserver reliability
in the 3D evaluation were 0.950 and 0.969, respectively. All of these values showed the high intra- and interobserver reliability of the current method.

**Changes in the Muscle Volume and Occupation Ratio of the SSP Before and After ARCR (2 Weeks)**

**Volume**

The mean SSP volume was 35.76 cm³ (SE, 1.75 cm³) before surgery and 36.34 cm³ (SE, 1.76 cm³) after surgery, and no significant difference was noted in the overall group (P = .372). The mean SSP volume did not change soon after surgery compared with before surgery in any patients (Figure 5).

*Group 1.* The mean SSP volume was 39.02 cm³ (SE, 5.60 cm³) before surgery and 36.88 cm³ (SE, 5.23 cm³) after surgery, and no significant difference was noted (P = .079).

*Group 2.* The mean SSP volume was 34.77 cm³ (SE, 1.57 cm³) before surgery and 36.18 cm³ (SE, 1.74 cm³) after surgery, and no significant difference was noted (P = .056).

*Group S.* The mean SSP volume was 36.59 cm³ (SE, 2.82 cm³) before surgery and 36.49 cm³ (SE, 2.86 cm³) after surgery, and no significant difference was noted (P = .907).

*Group M.* The mean SSP volume was 34.68 cm³ (SE, 1.76 cm³) before surgery and 36.15 cm³ (SE, 1.72 cm³) after surgery, and no significant difference was noted (P = .142).

**Occupation Ratio**

The mean occupation ratio was 48.10% (SE, 2.15%) before surgery and 49.87% (SE, 1.94%) after surgery, and no significant difference was noted in the overall group (P = .107). The mean occupation ratio increased significantly compared with the preoperative values in group 2 and group M, but no significant changes were noted in group 1 or group S (Figures 6-8).

*Group 1.* The mean occupation ratio was 55.47% (SE, 3.90%) before surgery and 53.63% (SE, 3.68%) after surgery, and no significant difference was noted (P = .310).

*Group 2.* The mean occupation ratio was 45.86% (SE, 2.38%) before surgery and 48.73% (SE, 2.26%) after surgery, and the difference was statistically significant (P = .028).

*Group S.* The mean occupation ratio was 54.16% (SE, 2.49%) before surgery and 53.07% (SE, 2.60%) after surgery, and no significant difference was noted (P = .343).

*Group M.* The mean occupation ratio was 40.19% (SE, 2.38%) before surgery and 45.68% (SE, 2.58%) after surgery, and significant change was noted (P = .003).

A post hoc power analysis showed a 1-β error probability (power) of 0.93 with an effect size of 1.05.

**DISCUSSION**

The most important finding of the present study was that the muscle volume of the SSP did not change in each group; thus, changes in the occupation ratios did not represent changes in the muscle volume in patients with moderate medial retraction or extended tearing in the transverse direction. To our knowledge, this is the first study to provide evidence that the occupation area of the SSP muscle can increase without recovery of atrophy due to structural changes caused by the operation.

**Evaluations of SSP Muscle Atrophy**

The quantitative MRI-based measurement of rotator cuff volumes has been reported to be a reliable method with good intra- and interobserver variability. However, our search of the literature did not reveal any studies in which the measurement of SSP volume was used to evaluate the muscle atrophy of the SSP.

Muscle atrophy of the SSP has previously been assessed using the occupation ratio of the cross-sectional area of the muscle belly to the supraspinatus fossa (estimated anatomic occupation area) along the oblique-sagittal plane on MRI. When that method is used, the cutting plane is defined by osseous landmarks, such as the scapular spine,
and the cutting plane is fixed in any series of examinations. However, the cutting plane of the muscle belly where the cross-sectional area is measured will change because the tendons are repaired by lateral traction toward the facet of the greater tuberosity. Previous studies have suggested that the cross-sectional area of the supraspinatus can increase immediately after surgery,\textsuperscript{6,9} and that increases in the occupation ratio may indicate not the recovery of the muscle volume but simply the change in the cutting plane of the muscle belly due to structural changes caused by the operation.\textsuperscript{12} Furthermore, Lhee et al\textsuperscript{9} reported that the increase in the occupation ratio seen soon after surgery depended on the degree of the preoperative SSP tendon’s medial retraction. However, in those studies, whether the changes in the occupation ratio represent changes in the muscle volume was not elucidated because the actual muscle volume was not assessed.

In the present study, the occupation ratio increased significantly soon after surgery compared with preoperative values in patients with moderate or more retraction of SSP, and the increase in the occupation ratio recognized soon after surgery depended on the degree of the preoperative SSP tendon’s medial retraction. This result was the same as reported in previous studies.\textsuperscript{9} In addition, we assessed the muscle volume and noted no significant changes compared with the preoperative values. Furthermore, we revealed that discordance could be seen in patients in whom both the SF and MF were affected. These findings indicated that the occupation ratio can change even if the muscle volume does not change significantly in patients with moderate medial retraction or extended tearing in the transverse direction.

**Time-Zero Study**

Jo et al\textsuperscript{6} reported that the occupation ratio can increase a mere 3 days after arthroscopic cuff repair compared with preoperative values; those investigators suggested...
that changes in the occupation ratios should be considered when assessing rotator cuff muscle changes by comparing the appearance on MRI before surgery with that at a certain time point after surgery. Their results were in line with the results of the present study. However, Jo et al. used 2 different MRI protocols in their comparison of 2 consecutive MRI examinations. In contrast, we used the same protocol in both of the consecutive examinations and showed that the occupation ratio can change soon after surgery. Our method may be more appropriate than theirs in terms of the uniformity of measurement.

Hamano et al. reported that greater muscle strength in abduction, better abduction range of motion, and higher Constant score at 2 years after ARCR were associated with improvement in the occupation ratio using MRI findings taken 2 weeks after surgery as a reference. Their results indicated that MRI findings taken soon after surgery were suitable as a time-zero reference. However, they studied only 2D findings and did not confirm whether the perioperative changes in the occupation ratio were associated with actual volumetric changes. However, our results revealed that the SSP muscle volume did not change soon after surgery compared with the preoperative values, and changes in the occupation ratio did not represent changes in the muscle volume in patients with moderate medial retraction or extended tearing in the transverse direction. The postoperative MRI findings may therefore be the most suitable for use as a time-zero reference.

Limitations

Several limitations associated with the present study warrant mention. First, we used T2-weighted images to segment the muscle, including the tendon, and to calculate the volume of the SSP. While this protocol was not originally developed for a 3D analysis, a previous study showed that the protocol was sufficient to assess muscle volume. Tingart et al. reported that calculating the muscle volume using 3D reconstruction of 2D MRI findings was a reliable method of determining the volumes of rotator cuff muscles. Those investigators measured the actual muscle volume of cadaveric shoulders by using water displacement and observed a significant correlation between the MRI findings obtained with a 2D imaging protocol and the actual muscle volume. According to their report, 3D reconstruction from 2D MRI findings appeared sufficient to determine the SSP volume. Furthermore, because the torn end of the tendon is well-defined on T2-weighted images, the protocol was suitable for accurately detecting the shape of the torn tendon. In the present study, comparison of the entire muscle volume, including the tendon and the internal fat, before and after surgery required strict segmentation of the muscle and tendon. Second, we arbitrarily divided the SSP and ISP according to the osseous landmark. The tendon of the SSP has conventionally been believed to attach to both the SF and MF, while the ISP simply attaches to the MF. However, recent studies have shown that the SSP attaches to the more anterior aspect of the humerus, including the lesser tuberosity, and the ISP attaches to the more anterior aspect of the humerus, including the SF, with the SSP and ISP overlapping at the SF. In the present study, the tendons attaching to the SF and MF were regarded as the SSP and ISP, respectively, because detecting the SSP and ISP tendon separately at the insertion was impossible due to pixel values on the MRI results, and because the topography of the repaired cuffs is not exactly the same as the normal anatomy. Thus, the addition of a component of the ISP tendon to the SSP tendon might affect the measured values. Third, the sample size was relatively small. However, the results of the post hoc power analysis showed that the effect size and 1-β error probability were sufficient.

CONCLUSION

The present study suggested that the occupation ratio can increase in size after an operation without volumetric changes. When a long-term observation of changes in the SSP volume after surgery is conducted, the postoperative MRI findings obtained soon after surgery—not before—should be used as a time-zero reference, especially in patients with moderate medial retraction or extended tearing in the transverse direction. We also recommend that volumetric measurements be performed in all future studies investigating SSP atrophy, while also determining whether SSP atrophy changes after surgery.

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REFERENCES


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