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Reliability and validity of a new deltoid muscle area measurement method after reverse shoulder arthroplasty

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Background: Accurate deltoid muscle assessment after reverse shoulder arthroplasty (RSA) is difficult using magnetic resonance imaging due to metal artifacts. We hypothesized that measuring the deltoid muscle area (DA) in the middle part of the deltoid's total length postoperatively would reduce metal artifacts and allow for an accurate assessment. This study aimed to assess the reliability and reproducibility of magnetic resonance imaging and evaluate its impact on postoperative outcomes.

Methods: The DA in the middle part of the muscle's total length was measured twice by four examiners using pre and postoperative magnetic resonance imaging in 60 patients who underwent RSA (22 men, 38 women; mean age: 77.4 years). The DA at the greater tuberosity was measured preoperatively, and its correlation with the middle part of the deltoid's total length was evaluated. The Constant-Murley Score was measured at 2 years postoperatively, and its correlation with the DA in the middle part of the deltoid's total length pre- and postoperatively was assessed.

Results: Intraclass correlation coefficients for intraobserver measurements of preoperative and postoperative DA in the middle part of the deltoid's total length were almost perfect, with mean values of 0.98 and 0.97, respectively. The intraclass correlation coefficients for interobserver reliability regarding the first and second DA measurements in the middle part of the deltoid's total length were 0.95 and 0.95 (preoperatively) and 0.89 and 0.90 (postoperatively). The Constant-Murley Score was assessed at 2 years postoperatively in 51 patients. Muscle strength was weakly and moderately correlated with preoperative DA ($r = 0.33$, $P = .02$) and postoperative DA ($r = 0.49$, $P < .01$), respectively.

Conclusion: DA measurement in the middle part of the deltoid's total length after RSA was not affected by metal artifacts and had excellent reproducibility. This measurement method positively correlated with postoperative muscle strength, suggesting its usefulness for predicting postoperative muscle strength.

Reverse shoulder arthroplasty (RSA) is a useful treatment for irreparable rotator cuff tear (RCT) and cuff tear arthropathy (CTA) for relieving pain and improving function. It increases the efficiency of the deltoid by increasing the tension and lever arm with a medialized center of rotation and extended upper limbs, particularly improving forward elevation and abduction.[1,2]

The RSA medializes the center of rotation of the glenoid and extends the deltoid lever arm. This is known to improve the efficiency of the deltoid, particularly in the direction of flexion and abduction.[1-3,20] Although many studies have reported on the biomechanics of the RSA, reports on the muscle properties of the deltoid are few. Moreover, these reports have assessed the quality of the deltoid muscle, including muscle area and degenerative change, which are known to correlate with postoperative outcomes.[3,7,10,12,15,22]

Several studies have reported a correlation between the muscle properties of the deltoid on magnetic resonance imaging (MRI) and preoperative outcomes. However, these were based on preoperative MRI findings only.[7,11,18,22] Therefore, developing a new postoperative measurement method is necessary.

MRI has superior soft tissue contrast, multiplanar capabilities, and a lack of ionizing radiation. Furthermore, it is ideal to evaluate the postoperative deltoid. However, accurate evaluation is limited by susceptibility artifacts due to metallic components.[9,14]

Osaka City University institutional review board approved this study (2021-277).

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Table I
Demographic and radiographic data.

Variables	Data
Age (years)	77.4 ± 5.0 (range, 65-88)
Gender (n)	Male, 22; Female, 38
Etiology (n)	CTA, 31; RCT, 29
Side of involvement (n)	Dominant, 44; Non-dominat, 16
Height (cm)	150.8 ± 9.2 (130-168)
Weight (kg)	54.4 ± 9.7 (32.7-73.8)
Body mass index (kg/m^2)	23.9 ± 3.6 (range, 15.3-34.5)
Diabetes (n)	Yes, 7; No, 53
Hypertension or any heart disease (n)	Yes, 21; No, 39
Shoulder usage level (n)	Daily life, 60
Fatty infiltration of the supraspinatus	3.06 ± 0.98
Fatty infiltration of the infraspinatus	2.90 ± 1.07
Fatty infiltration of the subscapularis	2.13 ± 1.22
Fatty infiltration of the teres minor	0.88 ± 1.08
Walch classification	A1, 60
Favard classification	E0, 3; E1, 57
Subscapularis repair	Yes, 49; No, 11

Therefore, in this study, to reduce metal artifacts, we evaluated the middle part of the total length of the deltoid muscle, which is less affected by the metal, instead of the position of the greater tuberosity, which is conventionally referred to as the area evaluation of the deltoid muscle.[11]

Moreover, muscle strength is important to obtain good clinical results following RSA. However, there are few reports on the relationship between muscle strength and deltoid muscle area (DA).[21,22] This study aimed to evaluate whether assessing DA in the middle part of the total length of the deltoid muscle would provide a reliable and reproducible assessment and assess the effect of DA on postoperative muscle strength and outcomes.

Materials and methods

Patients

This was a retrospective study recruiting 159 patients who underwent RSA between February 2017 and June 2019 at a single institution. Of the patients, 91 patients who underwent RSA with Aequalis Ascend Flex (Wright Medical, Memphis, TN, USA) were included. Informed consent was obtained from each patient, and ethical approval was obtained from the institutional review board.

The inclusion criteria were patients who underwent preoperative MRI and 6 months postoperative MRI with a diagnosis of CTA or irreparable RCT. Preoperative and postoperative radiographs were obtained and evaluated. The exclusion criteria were revision RSA; open reduction and internal fixation after proximal humerus fracture and dislocation or infection; and acute proximal humerus fracture. Finally, 60 patients were included in the study (CTA = 31, RCT = 29).

The average age of the patients was 77.4 ± 5.0 years (range, 65-88 years) (22 men and 38 women). The mean follow-up period was 2.0 ± 0.9 years (range, 0.5-4 years). The dominant shoulder was impacted in 44 patients, and the average height, weight, and body mass index were 150.8 ± 9.2 cm (130-168), 54.4 ± 9.7 kg (32.7-73.8), and 23.9 ± 3.6 kg/m^2 (15.3-34.5), respectively. Of the patients, 7 had diabetes mellitus, and 21 had hypertension or cardiovascular diseases. Regarding shoulder usage level, all patients showed a low level of daily activities only.

Fatty degeneration of the rotator cuff muscles was evaluated. The supraspinatus, infraspinatus, subscapularis, and teres minor tendons were assessed using preoperative MRI in accordance with the criteria by Goutallier et al.[6]

All patients' glenoid morphology was classified according to the Walch classification and Favard classification. All patients were classified as A1, 3 patients were classified as E0, and 57 patients were classified as E1.[16,19]

All procedures were performed using a standard deltopectoral approach. The subscapularis tendon was completely repaired, as far as possible. The subscapularis tendon was repaired in 49 patients and nonrepaired in 11 patients.

The patient demographic data are presented in Table I.

All patients underwent the same postoperative protocol with a sling for 2 weeks. Assisted range of motion exercise was started 2 days postoperatively, and free-range of motion exercise was started after weaning off the sling. The strengthening program was begun 3 months postoperatively.

MRI protocol

All MRI scans were performed on a 1.5 T Magnetom Essenza machine (Siemens Healthcare, Erlangen, Germany) with the humerus in a neutral position and the thumb pointing upward while the patient was in the supine position.

To reduce metal artifacts, the maximum radiofrequency bandwidth and high matrix values were used with Advanced WARP (Siemens Healthcare, Erlangen, Germany). Shoulder protocol with axial, coronal, and sagittal T1-weighted image sequences (repetition time/echo time of 580/8.6 ms, 2.2 mm slice thickness, 0 mm gap, 280 × 280 mm field of view). All scans were saved in Digital Imaging and Communications in Medicine format and reviewed by a fellowship-trained orthopedic shoulder and elbow surgeon to ensure there was no visible shoulder pathology.

Measurement of the DA

According to Henninger et al, the method of analysis of the muscle's cross-sectional area of the deltoid was taken on top of the greater tuberosity as a preoperative measurement (DA on the greater tuberosity).[11]

Regarding preoperative and postoperative measurements, true anteroposterior views of the humerus on radiography were taken with a 10 cm gauge. Additionally, the length of the midpoint between the lower edge of the acromion and the midpoint of the deltoid tuberosity was measured (Fig. 1, *A*, Fig. 2, *A*).

The magnification correction of deltoid length was measured as 10 cm × b ÷ a. Using the magnification correction of deltoid length, a transverse image was then made in the MRI coronal section at a line from the acromion to half of the deltoid length, and the deltoid cross-sectional area was measured. (Fig. 1, *B* and *C*; Fig. 2, *B* and *C*).

We measured both preoperative and postoperative MRIs and defined these as preoperative and postoperative DA, respectively.

Method of interobserver and intraobserver reliability

Preoperative and postoperative images of X-ray and MRI were provided to each of the four assessors, blinded to the identity of the patients. The assessors were three shoulder surgeons and one musculoskeletal radiologist.

The assessors repeated the measurement protocol for all images 1 month later, blinded to previous results, to assess for intraobserver reliability across the same measurement.

The order of the patients was randomized for each evaluation to avoid bias, and each reviewer was blinded to the measurements made by the other reviewers.

Clinical evaluation

Constant–Murley Scores were used to evaluate pain and shoulder function 2 years postoperatively.[5] Joint movements

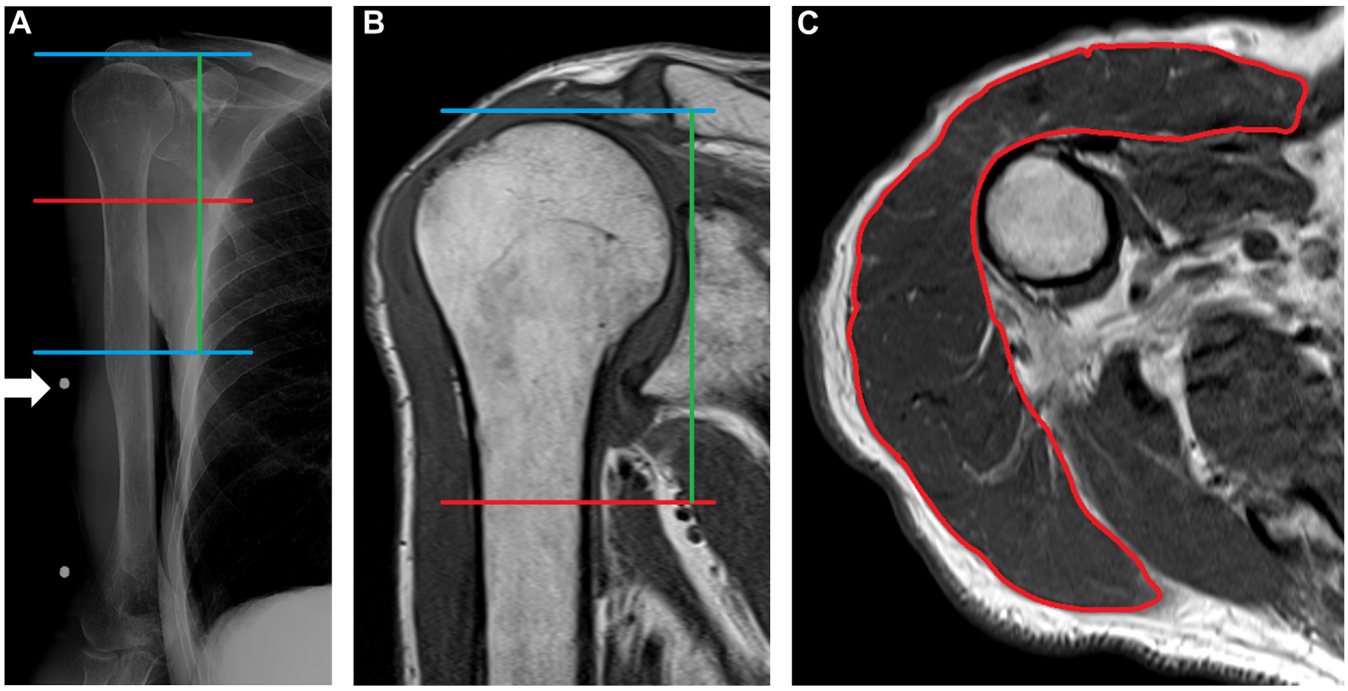

Figure 1 The measurement of preoperative DA. (**A**) True anteroposterior views of the humerus on X-ray is taken with a 10-cm gauge *(white arrow)*, and the length of the midpoint between the lower edge of the acromion *(blue line)* and midpoint of deltoid tuberosity *(blue line)* is measured *(red line)*. (**B**) A transverse image is then made in coronal magnetic resonance section at a line from the acromion to half of the deltoid length *(red line)*. (**C**) The deltoid cross-sectional area is measured. *DA*, deltoid muscle area.

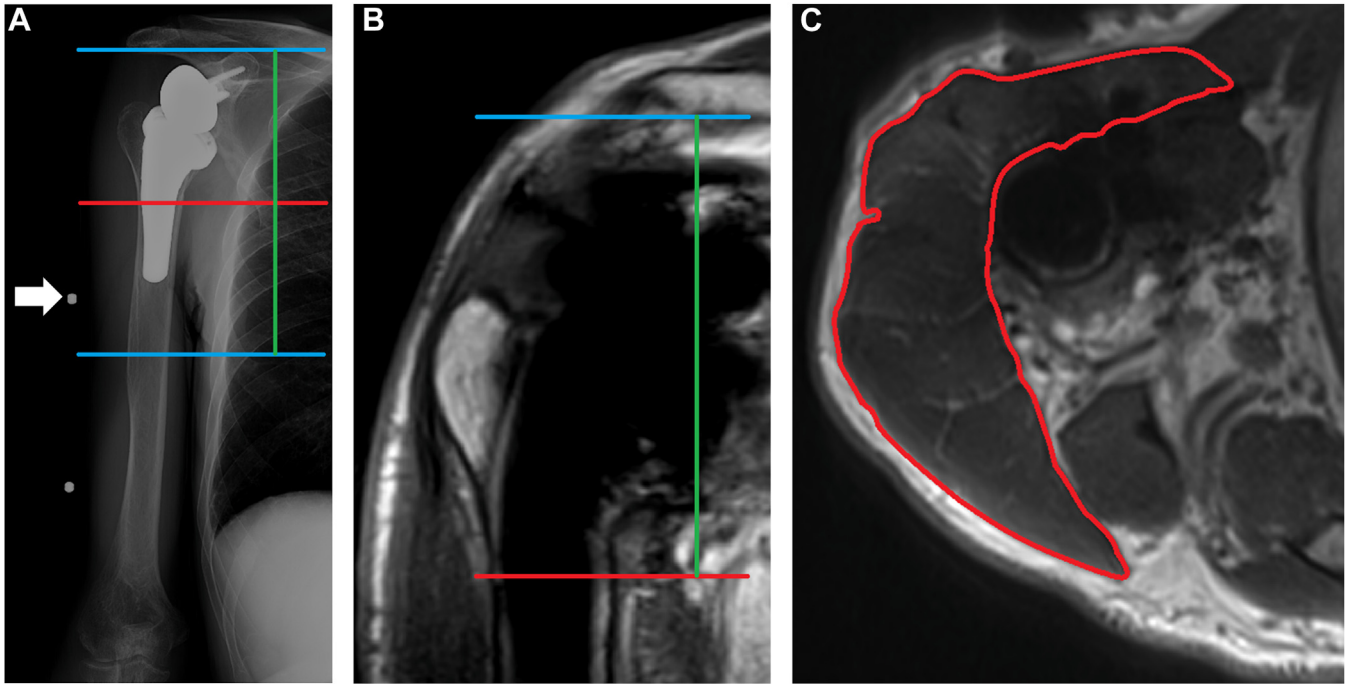

Figure 2 The measurement of preoperative DA. (**A**) True anteroposterior views of the humerus on X-ray is taken with a 10-cm gauge *(white arrow)*, and the length of the midpoint between the lower edge of the acromion *(blue line)* and midpoint of deltoid tuberosity *(blue line)* is measured *(red line)*. (**B**) Transverse image is then made in coronal magnetic resonance section at a line from the acromion to half of the deltoid length *(red line)*. (**C**) The deltoid cross-sectional area is measured. *DA*, deltoid muscle area.

were recorded with a goniometer. Regarding strength measurement as a subtest of the Constant–Murley Score, one end of a simple handheld band was held by the patient standing upright, with the upper extremity at a 90° abduction with an extended elbow and pronated forearm, 2 years postoperatively. (Fig. 3)

Figure 3 Muscle strength measurement method as a subtest of the Constant–Murley Score. One end of a simple handheld band was held by patient standing upright, with the upper extremity at a 90° abduction with extended elbow and pronated forearm.

Statistical methods

The mean value and standard deviation of each parameter were calculated using data from the first and second acquisition sessions. The Shapiro–Wilk test was used to test normality. A paired t-test was used for comparing differences in the values of preoperative and postoperative deltoid length and preoperative and postoperative DA. Intraclass correlation coefficients (ICCs) were calculated according to standard statistical methods (ICC 1,1 for intraobserver reliability and ICC 2,1 for interobserver reliability). The ICCs were classified as demonstrating slight (≤0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), or almost perfect agreement (0.81-1.00) The ICCs for intraobserver and interobserver reliability were calculated using data from both the first and second acquisition sessions.

Pearson correlation coefficients were used for evaluating the association between DA on the greater tuberosity and preoperative MRI and postoperative MRI, respectively, using data from the first and second acquisition sessions. Additionally, the relationship between pre- and postoperative MRI and the Constant-Murley Score was examined using Pearson correlation coefficients. The correlation coefficient was interpreted as weak (<0.35), moderate (0.35-0.70), or strong (>0.70). A prior sample-size calculation based on six raters, a 95% confidence interval (CI) of 0.2, and an ICC of >0.9, which is generally considered significant, indicated that a sample size of 47 was needed. Significance was set at $P < .05$. Statistical analyses were performed using the SPSS software (version 25.0; IBM, Armonk, NY, USA).

Results

Measurement of radiographic parameters

The mean preoperative deltoid length was 13.2 cm. The mean postoperative deltoid length was 15.1 cm, and the postoperative deltoid length was significantly longer than the preoperative deltoid length ($P < .01$). The DA on the greater tuberosity was 1944.3 mm^2. The mean preoperative DA was significantly larger than the mean postoperative DA (2209.8 mm^2 vs. 2118.5 mm^2, $P = .03$) (Table II).

Table II
Preoperative and postoperative measurement of deltoid length and DA.

Variables	Data
Prepoerative deltoid length (cm)	13.2 ± 1.2 (range, 10.7-15.9)
Postoperative deltoid length (cm)	15.1 ± 1.2 (range, 12.9-17.8)
Deltoid volume on the greater tuberosity (mm^2)	1944.3 ± 512.2 (range, 1099.9-3189.8)
Preoperative deltoid volume (mm^2)	2209.8 ± 651.8 (range, 1121.9-4229.0)
Postoperative deltoid volume (mm^2)	2118.5 ± 534.4 (range, 1056.8-3500.6)

DA, deltoid muscle area.

Intraobserver and interobserver reliability of the measurements

The ICCs for intraobserver and interobserver reliability of preoperative and postoperative DA are presented in Table III. The ICCs for intraobserver reliability of preoperative MRI were almost perfect for four examiners, with a mean value of 0.98 (range, 0.97-0.99). For postoperative MRI, the ICCs were almost perfect for four examiners, with a mean value of 0.97 (range, 0.95-0.99). The ICCs for interobserver reliability between the first and second measurements were almost perfect for the preoperative MRI (0.95 and 0.95) and postoperative MRI (0.89 and 0.90).

Correlation between preoperative DA and postoperative DA and DA on the greater tuberosity

DA on the greater tuberosity strongly correlated with the preoperative DA ($r = 0.75$, $P < .01$) and postoperative DA ($r = 0.73$, $P < .01$). Preoperative DA strongly correlated with postoperative DA ($r = 0.88$, $P < .01$) (Table IV).

Correlation between preoperative DA and postoperative DA and Constant-Murley Score

The Constant-Murley Score was assessed at 2 years postoperatively in 51 patients. Nine patients were excluded from the study. The follow-up rate was 85%.

The mean preoperative Constant-Murley Score was 37.0 ± 17.1 points (range, 8-77), and the mean preoperative muscle strength of the Constant-Murley Score was 2.6 ± 3.2 points (range, 0-11).

The mean postoperative Constant-Murley Score at 2 years was 63.8 ± 11.5 points (range, 34-80). Furthermore, the mean postoperative muscle strength of the Constant-Murley Score at 2 years was 7.4 ± 3.1 points (range, 2-17).

Muscle strength of the Constant-Murley Score correlated weakly with preoperative DA ($r = 0.33$, $P = .02$) and moderately with postoperative DA ($r = 0.49$, $P < .01$) (Table V).

Discussion

This study showed that preoperative RSA extended the postoperative deltoid muscle and reduced the area of the deltoid muscle. Moreover, the ICCs for both preoperative and postoperative DA evaluations in the middle part of the total length of the deltoid muscle were almost perfect in both intraobserver and interobserver reliability. In addition, they correlated with preoperative and postoperative DA at the greater tuberosity. The results indicated that this evaluation method was comparable to conventional evaluation. Furthermore, the preoperative and postoperative DA correlated with muscle strength assessed using the Constant–Murley Score at 2 years postoperatively.

Table III
Intraobserver and interobserver reliability for preoperative and postoperative DA.

	Preoperative deltoid volume	Postoperative deltoid volume
Intraobserver reliability		
Observer 1	0.985 (0.976-0.991)	0.955 (0.926-0.973)
Observer 2	0.966 (0.944-0.980)	0.954 (0.925-0.972)
Observer 3	0.993 (0.989-0.996)	0.991 (0.985-0.994)
Observer 4	0.968 (0.948-0.981)	0.983 (0.971-0.990)
Interobserver reliability		
1st measurement	0.945 (0.905-0.968)	0.892 (0.740-0.947)
2nd measurement	0.951 (0.922-0.970)	0.904 (0.805-0.948)

DA, deltoid muscle area; *CI*, confidence interval.
The values are given as the ICC, with the 95% CI, in parentheses.

Table IV
Correlation between preoperative DA and postoperative DA and DA on the greater tuberosity.

	Preoperative deltoid volume	Postoperative deltoid volume
Deltoid volume on the greater tuberosity		
Correlation coefficient (p)	0.746*	0.729
P value	.000	.000
		Postoperative deltoid volume
Preoperative deltoid volume		
Correlation coefficient (p)		0.875*
P value		.000

DA, deltoid muscle area.
*$P < .05$.

Table V
Correlation between DA and Constant–Murley Score.

	Preoperative deltoid volume	Postoperative deltoid volume
Constant–Murley Score		
Correlation coefficient (p)	−0.187	−0.129
P value	0.193	0.372
Muscle strength of Constant –Murley Score		
Correlation coefficient (p)	0.331*	0.487*
P value	.019	.000

DA, deltoid muscle area.
*$P < .05$.

In this study, RSA prolonged the deltoid length by an average of 1.9 cm, which resulted in an average decrease of 4.1% in the postoperative area compared with the preoperative area on MRI. This is in accordance with Koch et al's report that the muscle fiber area is reduced by the extension of the biopsy before and after surgery.[13] The present study indicated that the area of muscle area decreased due to the prolongation of deltoid length. This reduction in muscle area may also be due to early postoperative inactivity and growth due to new length and function later on.

We also investigated a reproducible evaluation method for measuring the area of this changing DA. In general, after arthroplasty, the use of MRI is limited by metal artifacts caused by metallic components. Protocols to reduce metal artifacts during MRI are becoming more common, and image quality is improving. MRI can detect several postoperative complications of shoulder arthroplasty, such as infections, neuropathy, component loosening,

tendon and muscle abnormalities, or glenoid wear in cases of partial joint replacement.[4,8,14,17] However, with the conventional method of assessing DA, accurate assessment is often difficult due to metal artifacts after RSA.[9]

Based on measuring DA in the middle part of the total length of the deltoid muscle, our method could reduce metal artifacts and evaluate DA with high accuracy, and the ICCs of intraobserver reliability were 0.97-0.99 and interobserver reliability were 0.94-0.95 in the evaluation of preoperative DA. Moreover, in the evaluation of postoperative DA, ICCs of intraobserver and interobserver reliability were 0.95-0.99 and 0.89-0.91, respectively. In previous reports of DA, the intraobserver reliability has been reported to be approximately 0.74-0.97, and the interobserver reliability was approximately 0.77-0.94. In our study, both interobserver and intraobserver reliability were approximately 0.9, which is comparable to that in other reports. Therefore, these measurement methods might have excellent reliability and validity.

In a cadaveric study, Henninger et al have reported that DV at the top of the greater tuberosity on MRI could predict deltoid volume.[11] In this present study, both preoperative and postoperative DA correlated with DA on the greater tuberosity, suggesting that it may correlate with actual deltoid volume.

Our results suggest that preoperative and postoperative DA were highly reproducible regardless of the influence of examiners and may be used in the same way as conventional DA measurement. Moreover, our measurement method was less susceptible to postoperative metal artifacts. Therefore, it has the advantage of being able to measure changes between preoperative and postoperative DA and may be used as a new method of measuring DA before and after RSA. However, the effect of a small postoperative area loss must be considered regarding metal artifacts.

In our study, the Constant-Murley Score for muscle strength correlated with both preoperative and postoperative DA. Turkmen et al have reported that preoperative and postoperative changes in deltoid volume correlated with the postoperative American Shoulder and Elbow Surgeons score and Constant-Murley Score.[18] Yoon et al have reported that preoperative deltoid volume divided by body mass index correlated with postoperative Constant−Murley Score. Wiater et al also have reported that preoperative deltoid volume was similarly correlated with American Shoulder and Elbow Surgeons score, Constant-Murley Score, and Constant-Murley Score for muscle strength.[21,22] Meanwhile, the postoperative DA in this study was moderately correlated with the postoperative muscle strength of the Constant-Murley Score, and our measurement method may be useful for predicting postoperative muscle strength.

This study has several limitations. First, the number of patients was small. Nevertheless, the number of patients was larger than that in other deltoid volume studies, and the required number of patients was met using the power analysis. Second, there might have been a possibility of measurement error in preoperative and postoperative DA and radiological parameters. However, the ICC was perfect for both intraobserver and interobserver reliability of the measurements. Third, not all cases were followed up, and the follow-up period was short. Fourth, this was a retrospective study. Fifth, since this was a single-center study, further evaluation at other institutions is necessary. Last, the evaluation was conducted on a single implant, and it is necessary to consider other implants in the future.

Conclusion

The measurement of DA in the middle part of the total length of the deltoid after RSA was not affected by metal artifacts and had excellent reproducibility. This new method was useful for measuring the deltoid muscle after RSA. Moreover, this measurement method positively correlated with postoperative muscle strength, suggesting its usefulness for predicting postoperative muscle strength.

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