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Fatty Degeneration of the Rotator Cuff Muscles Improves in Shoulders with Successful Arthroscopic Rotator Cuff Repair

A Prospective Study Using Quantitative T2 Mapping Techniques, with 2-Year Follow-up

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Background: There remain arguments regarding whether fatty degeneration of the rotator cuff muscles improves following rotator cuff repair. The purpose of this study was to prospectively investigate changes in fatty degeneration of the rotator cuff muscles, quantitatively measured on magnetic resonance imaging (MRI) with use of transverse relaxation time (T2) mapping techniques, and to assess the relationship between these changes and clinical outcomes.

Methods: Patients were included if they were scheduled for arthroscopic rotator cuff repair using the suture-bridge technique between June 2014 and December 2015, underwent preoperative MRI including the T2 mapping sequence, and consented to participate in the study. Exclusion criteria consisted of trauma within 2 months before preoperative MRI, isolated subscapularis tears, patch augmentation, neuromuscular disease, and a follow-up duration of <2 years. MRI scans were acquired preoperatively and at 2 years postoperatively, and T2 values of the supraspinatus and infraspinatus muscles were measured, with smaller T2 values indicating less fat content. Shoulders were evaluated on the basis of active range of motion (ROM), Constant and University of California Los Angeles Shoulder Rating Scale scores, shoulder external rotation strength with the arm at the side, and rotator cuff integrity on postoperative MRI.

Results: A total of 103 patients (103 shoulders) with a mean age of 65 ± 9 years (range, 42 to 83 years) were included, of whom 52 were male and 51 were female. There were 13 partial, 18 small, 35 medium, 33 large, and 4 massive tears. Concomitant subscapularis tears were observed in 35 shoulders. Overall, ROM, clinical scores, and external rotation strength significantly improved postoperatively. Retears were found in 27 shoulders (26%). External rotation strength significantly improved postoperatively only in shoulders without a retear. Among shoulders without a retear, the postoperative T2 values of the supraspinatus and infraspinatus were significantly smaller than the preoperative values ($p < 0.001$ for both); however, no improvement was seen in shoulders with a retear.

Conclusions: Shoulders with successful repair demonstrated significantly smaller T2 values postoperatively as well as significantly improved external rotation strength. Fatty degeneration of the cuff muscles can be reversed, at least in part, and muscle strength improves in shoulders with successful repair.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Arthroscopic rotator cuff repair has become the standard surgical treatment for rotator cuff tears, and good clinical outcomes have been reported[1-3]. Fatty degeneration of the rotator cuff muscles has been reported as one of the factors influencing clinical outcomes following rotator cuff repair[4-6]. Many studies have also reported that preoperative fatty

Disclosure: No external funding was received for this work. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A586).

degeneration of the rotator cuff muscles is associated with postoperative retears and poor outcomes following arthroscopic repair[4,7-11].

There remain arguments regarding whether fatty degeneration of the rotator cuff muscles improves following rotator cuff repair[12-19]. Several studies have concluded that fatty degeneration does not improve even after successful repair[12,13,18,19], whereas other studies have found improvement in fatty degeneration postoperatively[14-17]. One controversial factor in prior studies is the site at which fatty degeneration of the muscles was evaluated. Rotator cuff muscles have commonly been assessed on the Y-view, specifically on the most lateral of the oblique sagittal images in which the scapular spine remains in contact with the scapular body[20,21]. Yoo et al.[22] reported that the supraspinatus muscle is mobile at the Y-view level because the muscle is not attached to the suprascapular fossa. Given the muscle shift caused by rotator cuff repair, a few studies have recommended evaluating the muscles at a more medial site in order to minimize measurement error when comparing pre- and postoperative fatty degeneration[22,23].

Another factor may be the evaluation methods utilized in these studies. Most of these studies employed semiquantitative methods such as the Goutallier staging[9,24] for the evaluation of fatty degeneration[13,15,18]; however, poor intra- and interrater reliability have been reported for these methods[25,26]. In addition, small changes may be overlooked when using semiquantitative methods because such methods only evaluate fatty degeneration in stages. These issues may account for the disagreement in the literature regarding postoperative changes in fatty degeneration.

Recently, several techniques using magnetic resonance imaging (MRI), such as MR spectroscopy[27,28] and the Dixon sequence[10,29,30], have been introduced to quantitatively evaluate fatty degeneration of the rotator cuff muscles. However, MR spectroscopy does not allow for spatially resolved measures[31], and a Dixon sequence only calculates the muscle-to-fat ratio[10,29,30]. Transverse relaxation time (T2) mapping, with which many recent MRI systems are equipped, has been reported to be able to quantitatively evaluate fatty degeneration of the rotator cuff muscles by measuring T2 values with very high intra- and interobserver reliability[32]. T2 mapping techniques have the potential to precisely assess postoperative changes in fatty degeneration in combination with the measurement of the medial muscles to minimize the influence of the postoperative muscle shift.

The purpose of this study was to prospectively investigate changes in fatty degeneration of the rotator cuff muscles, quantitatively measured with use of T2 mapping techniques at the medial site, and to assess the relationships between these changes and clinical outcomes. We hypothesized that fatty degeneration, as well as clinical outcomes, would improve in shoulders with a successful repair.

Materials and Methods

Patients

The study protocol was approved by the institutional review board of our hospital. Between June 2014 and December 2015, we prospectively recruited study candidates at our institute. Patients were included if they were scheduled for arthroscopic rotator cuff repair using the suture-bridge technique, underwent preoperative MRI including the T2 mapping sequence, and consented to participate in the study. The exclusion criteria were trauma within 2 months before preoperative MRI, isolated subscapularis tears, patch augmentation, neuromuscular disease, and a follow-up duration of <2 years. All patients who were scheduled for arthroscopic rotator cuff repair at our institute were asked to participate in the study and were provided with a detailed explanation of the study protocol. Patients who agreed to participate gave informed consent. A power analysis indicated that 140 patients were required (α, 0.05; effect size, 0.6; power, 0.8).

MRI Acquisition

For all patients, MRI scans were acquired preoperatively and at 2 years postoperatively with use of the Intera 1.5T MRI scanner (Philips). A T2 mapping sequence was performed in addition to routine diagnostic imaging, which included T1-weighted oblique sagittal images and T2-weighted oblique coronal, oblique sagittal, and axial images. The T2 mapping was performed with use of the multi-spin-echo sequence on a sagittal image 15 mm medial to the Y-view to minimize measurement errors caused by the postoperative muscle shift[8,22,23]. The scanning parameters are presented in Table I.

TABLE I Scanning Parameters*

	T1-Weighted, Oblique Sagittal	T2-Weighted, Oblique Sagittal	T2-Weighted, Oblique Coronal	T2-Weighted, Axial	T2 Mapping
TR *(msec)*	400-600	4,200	5,000	4,000	1,500
TE *(msec)*	11	100	100	100	11, 22, 33, 44, 55, 66, 77, 88
FOV *(mm)*	160	160	160	160	200
Matrix	720 × 720	720 × 720	800 × 800	720 × 720	320 × 320
Thickness *(mm)*	3.5	3.5	3.5	3.5	5.0

*TR = repetition time, TE = echo time, FOV = field of view.

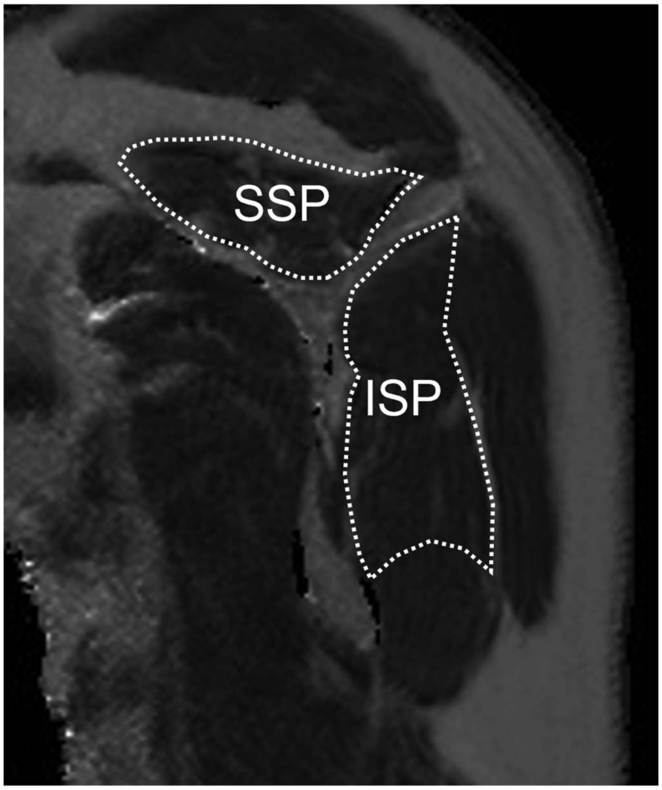

Fig. 1
T2 measurement. Regions of interest were manually drawn along the muscle borders on T2-calculated images, and the mean T2 values were computed. SSP = supraspinatus, ISP = infraspinatus.

T2 Measurement

The measurement of T2 values was performed according to the techniques utilized in a previous study[23]. A single experienced shoulder surgeon who was blinded to patient data measured the T2 values of the supraspinatus and infraspinatus muscles with use of a PACS (picture archiving and communication system) workstation (Doctor PACS for; Doctor-NET). The mean T2 values of the supraspinatus and infraspinatus were computed by drawing the regions of interest along the muscle borders on T2-calculated images (Fig. 1). Degenerated muscles were expected to have larger T2 values reflecting their increased fat content[32]. The reported intra- and interobserver reliabilities of T2 measurement were >0.95[32].

MRI Evaluation

A single experienced shoulder surgeon evaluated the MRI scans. Fatty degeneration of the supraspinatus and infraspinatus muscles was assessed on T1-weighted oblique sagittal images with use of Goutallier staging[9,20,24]. Repair integrity was evaluated on postoperative MRI with use of the Sugaya classification[33], and grades IV and V were regarded as indicating a retear.

Clinical Assessment

One of the senior surgeons evaluated patients pre- and postoperatively. Active range of motion (ROM), including flexion, external rotation with the arm at the side, and internal rotation with the arm at the side; external rotation strength; the Constant score; and the University of California Los Angeles (UCLA) Shoulder Rating Scale score were assessed preoperatively and at 2 years postoperatively. Flexion and external rotation were measured with use of a goniometer. Internal rotation was measured as the highest spine level reachable with the thumb. With use of a handheld dynamometer, isometric external rotation strength was measured with the arm at the side in neutral shoulder rotation with 90° of elbow flexion, as described in a previous study[15] (Fig. 2).

Surgical Technique

Patients underwent surgery in the beach chair position under general anesthesia and an interscalene block. The operations were performed by one of the senior surgeons or by one of the fellow surgeons under the supervision of senior surgeons. After the glenohumeral joint and the subacromial bursa were investigated arthroscopically, subacromial decompression was performed in all cases. The rotator cuff tear size was

Fig. 2
Measurement of external rotation strength. The patient sat on a chair with the arm in neutral rotation at the side and with the elbow in 90° of flexion. Isometric external rotation strength was measured with the handheld dynamometer applied on the distal forearm.

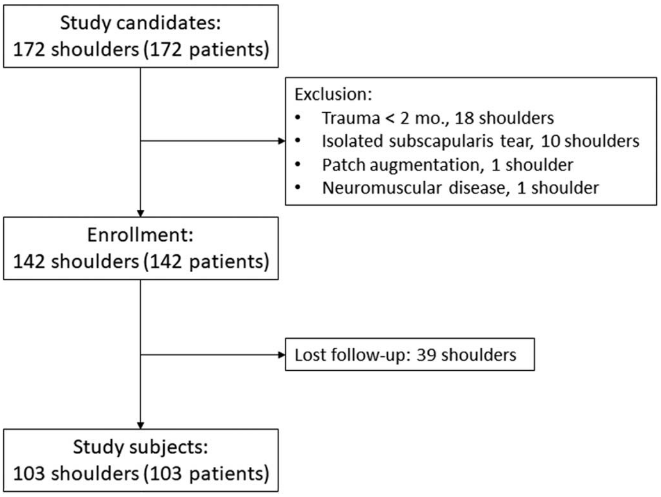

Fig. 3
Patient selection.

determined according to the DeOrio and Cofield classification[34]: small, ≤1 cm in mediolateral width; medium, >1 to ≤3 cm; large, >3 to ≤5 cm; massive, >5 cm.

For shoulders with poor tendon mobility, coracohumeral ligament resection and capsular release were performed. Tendons with partial-thickness tears were made into full-thickness tears and repaired as such. Triple-loaded suture anchors (HEALIX ADVANCE BR Anchor; Depuy Synthes) were inserted at the medial border of the greater tuberosity, and 2 suture limbs at a time were passed through the cuff with use of a suture grasper. Two pairs of suture limbs were fixed with use of lateral-row knotless suture anchors (HEALIX ADVANCE Knotless Anchor [Depuy Synthes] and SwiveLock C Anchor [Arthrex]). Then, the remaining sutures were tied to avoid the concentration of stress on the medial-row sutures[3]. We usually use 1 or 2 anchors each for the medial and lateral rows in smaller tears and 2 or 3 anchors each in larger tears.

A suture-bridge technique was also utilized for the repair of concomitant subscapularis tears[35]. Tenodesis or tenotomy of the long head of the biceps (LHB) was performed in shoulders with rotator cuff tears larger than medium in size or with LHB inflammation or laceration[36]. Generally, we performed tenodesis for males <70 years of age and females <65 years of age and performed tenotomy for older patients.

Postoperative Treatment

A sling with an abduction pillow was utilized to immobilize shoulders for 4 to 5 weeks, depending on the repair quality. Rehabilitation began with the relaxation of the shoulder girdle muscles the day after surgery, followed by passive ROM and isometric cuff exercises. After the removal of the brace, active-assisted ROM exercises were started and active exercises followed. Depending on their functional recovery, patients were allowed to return to work or sports at 3 months postoperatively for light activities and at 6 months postoperatively for heavy activities.

Statistical Analysis

A paired t test or Wilcoxon signed-rank test was utilized to compare pre- and postoperative data. A Student t test, Mann-Whitney U test, or chi-square test was utilized for the comparison of 2 groups. A Pearson correlation coefficient test was utilized to examine the relationship between 2 parameters. The level of significance was set at $p < 0.05$.

Results

Patients

A total of 172 patients (172 shoulders) met the inclusion criteria. Thirty patients (30 shoulders) were excluded for

TABLE II Pre- and Postoperative Shoulder Function*

	Preop.	Postop.	P Value
ROM			
Flexion *(deg)*	148 ± 30	166 ± 11	<0.001
External rotation *(deg)*	44 ± 19	50 ± 14	0.003
Internal rotation	T12 ± 3	T10 ± 3	<0.001
External rotation strength *(Nm)*	2.7 ± 1.5	3.6 ± 2.0	<0.001
Constant score	60 ± 15	87 ± 10	<0.001
UCLA score	19 ± 5	33 ± 3	<0.001

*Values are given as the mean ± standard deviation, except as noted.

TABLE III Pre- and Postoperative MRI Evaluation of the Rotator Cuff Muscles*

	Preop.	Postop.	P Value
T2 value *(msec)*			
Supraspinatus	61.5 ± 11.1	58.5 ± 11.1	0.005
Infraspinatus	56.5 ± 11.1	55.3 ± 12.2	0.09
Goutallier stage *(no. of shoulders)*			
Supraspinatus			0.5
0	3	3	
1	14	12	
2	78	80	
3	8	7	
4	0	1	
Infraspinatus			0.8
0	5	3	
1	34	41	
2	56	49	
3	6	6	
4	2	4	

*Values are given as the mean ± standard deviation or as the count, except as noted.

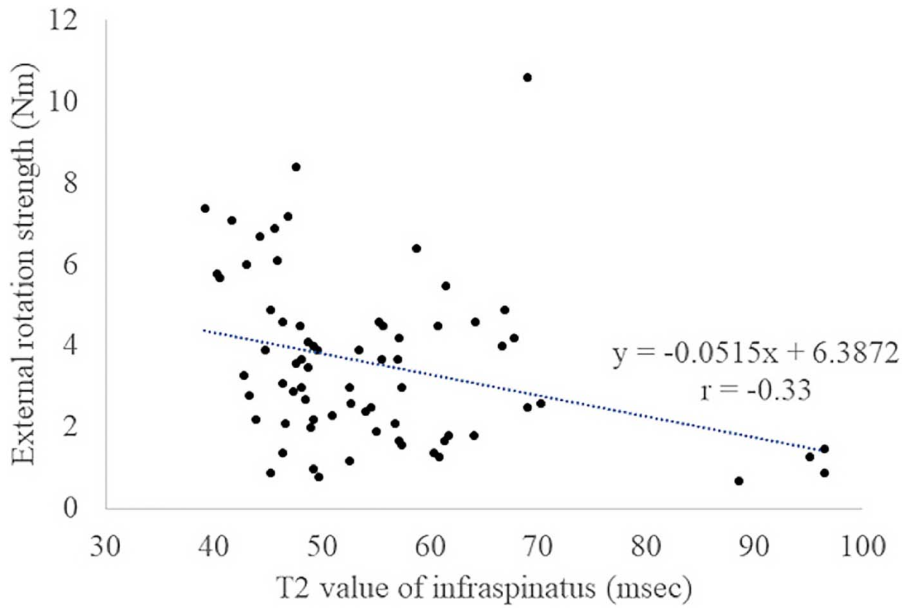

Fig. 4

Correlation between the T2 value of the infraspinatus and the external rotation strength. The postoperative T2 value of the infraspinatus was negatively correlated with postoperative external rotation strength (r = −0.33; p = 0.006).

the following reasons: trauma within 2 months before MRI (18 shoulders), isolated subscapularis tear (10 shoulders), patch augmentation (1 shoulder), and neuromuscular disease (1 shoulder). Thus, 142 patients (142 shoulders) were enrolled in this study; however, 39 patients were lost to follow-up before 2 years postoperatively. Consequently, the subjects of this study were 103 shoulders (103 patients), and the follow-up rate was 73% (Fig. 3).

The shoulders included in the study were in 52 male and 51 female patients with a mean age (and standard deviation) of 65 ± 9 years (range, 42 to 83 years). There were 13 partial, 18 small, 35 medium, 33 large, and 4 massive rotator cuff tears. Concomitant subscapularis tears were observed in 35 shoulders.

Overall Outcomes

ROM in all directions significantly improved postoperatively (flexion, $p < 0.001$; external rotation, p = 0.003; internal rotation, $p < 0.001$; Table II). External rotation strength also showed significant improvement ($p < 0.001$). The Constant and UCLA scores significantly improved postoperatively as well ($p < 0.001$ for each).

The postoperative T2 values of the supraspinatus were significantly smaller than the preoperative values (p = 0.005; Table III). No significant changes were detected between the pre- and postoperative T2 values of the infraspinatus. The postoperative T2 value of the infraspinatus was negatively correlated with postoperative external rotation strength (r = −0.33; p = 0.006; Fig. 4). There was no significant change postoperatively in the Goutallier stage of the supraspinatus or infraspinatus.

Comparison Between Intact Shoulders and Shoulders with a Retear

Retears were observed in 27 shoulders (26%) (Table IV). Demographic data did not significantly differ between shoulders without a retear (i.e., intact shoulders) and shoulders with a retear except for age (p = 0.02) and tear size (p = 0.006).

There were no significant differences in pre- and postoperative ROM between the intact and retear groups. Both

TABLE IV Comparison of Demographic Data Between Shoulders with and without a Retear

	Intact	Retear	P Value
No. of shoulders	76	27	
Sex *(no. of patients)*			0.8
Male	39	13	
Female	37	14	
Age *(yr)*	64 ± 9	69 ± 8	0.02
Height *(cm)*	161 ± 8	159 ± 8	0.3
Weight *(kg)*	62 ± 12	63 ± 16	0.6
Body mass index*(kg/m²)*	23.8 ± 3.8	25.1 ± 5.5	0.2
Operative side *(no. of shoulders)*			0.4
Dominant	53	21	
Nondominant	23	6	
Tear size *(no. of shoulders)*			0.006
Partial	13	0	
Small	17	1	
Medium	25	10	
Large	19	14	
Massive	2	2	

TABLE V Comparison of Shoulders with and without a Retear*

		Intact	Retear	P Value
ROM				
Flexion *(deg)*	Preop.	146 ± 33	154 ± 21	0.2
	Postop.	167 ± 10	166 ± 15	0.8
	P value	<0.001	0.01	
External rotation *(deg)*	Preop.	45 ± 20	42 ± 18	0.5
	Postop.	52 ± 14	46 ± 15	0.07
	P value	0.002	0.3	
Internal rotation	Preop.	T12 ± 4	L1 ± 3	0.05
	Postop.	T10 ± 3	T11 ± 3	0.1
	P value	<0.001	<0.001	
External rotation strength *(Nm)*	Preop.	2.8 ± 1.4	2.2 ± 1.6	0.1
	Postop.	4.0 ± 2.1	2.5 ± 1.6	0.008
	P value	<0.001	0.2	
Constant score	Preop.	61 ± 14	58 ± 18	0.4
	Postop.	88 ± 9	84 ± 14	0.07
	P value	<0.001	<0.001	
UCLA score	Preop.	19 ± 3	19 ± 8	0.8
	Postop.	33 ± 3	32 ± 4	0.03
	P value	<0.001	<0.001	
T2 value *(msec)*				
Supraspinatus	Preop.	59.9 ± 11.0	66.2 ± 10.2	0.01
	Postop.	54.4 ± 7.1	70.3 ± 11.9	<0.001
	P value	<0.001	0.06	
Infraspinatus	Preop.	55.0 ± 9.4	60.8 ± 14.1	0.02
	Postop.	52.2 ± 8.4	64.3 ± 16.3	<0.001
	P value	<0.001	0.02	
Goutallier stage *(no. of shoulders)*				
Supraspinatus	Preop.			<0.001
	0	3	0	
	1	13	1	
	2	55	23	
	3	5	3	
	4	0	0	
	Postop.			<0.001
	0	3	0	
	1	12	0	
	2	60	20	
	3	1	6	
	4	0	1	
	P value	0.6	0.3	
Infraspinatus	Preop.			0.006
	0	5	0	
	1	29	5	
	2	38	18	
	3	4	2	
	4	0	2	

continued

TABLE V (*continued*)

		Intact	Retear	P Value
	Postop.			<0.001
	0	3	0	
	1	38	3	
	2	31	18	
	3	4	2	
	4	0	4	
	P value	0.1	0.1	

*Values are given as the mean ± standard deviation or as the count, except as noted.

groups demonstrated significant improvement in ROM in all directions except in external rotation, which was not significantly improved in the retear group (Table V). Intact shoulders showed significant improvement in external rotation strength ($p < 0.001$); however, no significant improvement in external rotation strength was detected in shoulders with a retear. Postoperative external rotation strength was significantly greater in the intact group than in the retear group (p =

TABLE VI Comparison of Shoulders with and without a Retear in the Smaller-Tear Subgroup*

		Intact (N = 55)	Retear (N = 11)	P Value
ROM				
Flexion *(deg)*	Preop.	148 ± 31	155 ± 17	0.5
	Postop.	167 ± 10	166 ± 8	0.9
	P value	<0.001	0.06	
External rotation *(deg)*	Preop.	45 ± 20	50 ± 12	0.5
	Postop.	52 ± 13	46 ± 15	0.6
	P value	0.002	0.3	
Internal rotation	Preop.	T12 ± 4	L1 ± 3	0.3
	Postop.	T10 ± 3	T12 ± 3	0.2
	P value	<0.001	0.06	
External rotation strength *(Nm)*	Preop.	3.3 ± 1.3	2.7 ± 1.4	0.3
	Postop.	4.3 ± 2.2	2.8 ± 2.2	0.1
	P value	0.004	0.5	
Constant score	Preop.	61 ± 13	60 ± 17	0.9
	Postop.	87 ± 9	81 ± 19	0.1
	P value	<0.001	<0.001	
UCLA score	Preop.	19 ± 3	17 ± 4	0.07
	Postop.	33 ± 3	31 ± 5	0.1
	P value	<0.001	<0.001	
T2 value *(msec)*				
Supraspinatus	Preop.	56.9 ± 8.7	60.5.2 ±10.1	0.2
	Postop.	53.5 ± 6.5	65.8± 14.8	<0.001
	P value	0.001	0.2	
Infraspinatus	Preop.	52.1 ± 7.4	56.4 ± 7.5	0.08
	Postop.	50.1 ± 7.4	60.4 ± 14.1	0.001
	P value	0.01	0.1	

*Values are given as the mean ± standard deviation, except as noted.

TABLE VII Comparison of Shoulders with and without a Retear in the Larger-Tear Subgroup*

		Intact (N = 21)	Retear (N = 16)	P Value
ROM				
Flexion *(deg)*	Preop.	141 ± 36	153 ± 24	0.2
	Postop.	166 ± 10	166 ± 18	0.9
	P value	0.003	0.1	
External rotation *(deg)*	Preop.	47 ± 19	44 ± 17	0.6
	Postop.	50 ± 16	43 ± 16	0.2
	P value	0.4	1.0	
Internal rotation	Preop.	T11 ± 3	L2 ± 3	0.06
	Postop.	T11 ± 3	T11 ± 3	0.9
	P value	0.1	<0.001	
External rotation strength *(Nm)*	Preop.	1.8 ± 0.9	2.0 ± 1.8	0.8
	Postop.	3.0 ± 1.2	2.4 ± 1.3	0.2
	P value	0.002	0.4	
Constant score	Preop.	60 ± 16	56 ± 19	0.5
	Postop.	91 ± 5	86 ± 10	0.04
	P value	<0.001	<0.001	
UCLA score	Preop.	19 ± 4	20 ± 10	0.7
	Postop.	34 ± 2	32 ± 4	0.08
	P value	<0.001	0.001	
T2 value *(msec)*				
Supraspinatus	Preop.	67.6 ± 12.9	70.1 ± 8.5	0.5
	Postop.	56.6 ± 8.3	73.4 ± 8.7	<0.001
	P value	<0.001	0.2	
Infraspinatus	Preop.	62.6 ± 10.2	63.9 ± 16.8	0.8
	Postop.	56.6 ± 9.4	66.9 ± 17.6	0.003
	P value	0.01	0.08	

*Values are given as the mean ± standard deviation, except as noted.

0.008). The Constant and UCLA scores showed significant improvement postoperatively in both groups ($p < 0.001$ for each). The postoperative Constant score did not significantly differ between the groups, whereas the UCLA score was significantly better in the intact group ($p = 0.03$).

Among intact shoulders, the postoperative T2 values of the supra- and infraspinatus were significantly smaller than the preoperative values ($p < 0.001$ for both). Among shoulders with a retear, the pre- and postoperative T2 values of the supraspinatus did not significantly differ, but the postoperative T2 values of the infraspinatus were significantly larger than the preoperative T2 values ($p = 0.02$). Compared with shoulders with a retear, those without a retear had significantly smaller pre- and postoperative T2 values of the supraspinatus ($p = 0.01$ and $p < 0.001$, respectively) and the infraspinatus ($p = 0.02$ and $p < 0.001$, respectively).

Comparison Between Smaller and Larger Tears

We analyzed the data by dividing the subjects into those with smaller tears (i.e., partial to medium tears; 66 shoulders) and those with larger tears (i.e., large to massive tears; 37 shoulders). In the smaller-tear group, intact shoulders demonstrated significant improvement in ROM (flexion, $p < 0.001$; external rotation, $p = 0.002$; internal rotation, $p < 0.001$) and external rotation strength ($p = 0.004$)(Table VI), whereas shoulders with a retear did not demonstrate any significant changes in these measures. The postoperative supraspinatus and infraspinatus T2 values among intact shoulders were significantly smaller than the preoperative values in those shoulders ($p = 0.001$ and $p = 0.01$, respectively) as well as significantly smaller than the postoperative T2 values among shoulders with a retear ($p < 0.001$ and $p = 0.001$, respectively).

In the larger-tear group, external rotation strength significantly improved only in intact shoulders ($p = 0.002$; Table VII). The postoperative supraspinatus and infraspinatus T2 values among intact shoulders were significantly smaller than the preoperative values among those shoulders ($p < 0.001$ and $p = 0.01$, respectively) as well as significantly smaller than the postoperative values among shoulders with a retear (supraspinatus, $p < 0.001$; infraspinatus, $p = 0.003$). Compared with intact shoulders in the smaller-tear group, those in the larger-tear group demonstrated a greater change between the pre- and postoperative T2 values of the supraspinatus ($p < 0.001$) and the infraspinatus ($p = 0.007$).

Discussion

The results of this study demonstrated that the T2 values of the supraspinatus and infraspinatus decreased after successful repair; however, no significant decrease in T2 values was detected among shoulders with a retear. External rotation strength significantly improved in shoulders without a retear but no significant change in external rotation strength was observed in shoulders with a retear. Postoperative external rotation strength was negatively correlated with the postoperative T2 value of the infraspinatus.

Among intact shoulders, the postoperative T2 values of the supraspinatus and infraspinatus were significantly smaller than the preoperative values. Given that the T2 values of the rotator cuff muscles are thought to reflect the degree of fatty degeneration[32], this finding indicates that fatty degeneration can be reversed if the tendons are successfully repaired. Postoperative changes in the fatty degeneration of the rotator cuff muscles have continued to be debated in the literature, and evaluation methods may play a role in this dispute. In fact, similar to previous studies[13,18], we did not find a significant change in the Goutallier stage of the supraspinatus or infraspinatus postoperatively. We believe that the present study provides reliable data on the postoperative change in fatty degeneration, as the influence of the muscle shift due to tendon repair is negligible when quantitative evaluation is performed at the medial site.

A previous study indicated that more severe fatty degeneration of the rotator cuff muscles is correlated with a lower degree of muscle strength[37]. In the present study, the postoperative T2 value of the infraspinatus was negatively correlated with postoperative external rotation strength, which implies that T2 values have the potential to reflect muscle strength. Additionally, intact shoulders demonstrated significantly improved external rotation strength as well as significantly smaller T2 values postoperatively. Although the mean change in the T2 values of the infraspinatus in intact shoulders was only 2.8 msec, our findings suggest that the change was clinically meaningful.

Shoulders with a retear showed no significant improvement in external rotation strength postoperatively; however, significant improvements were detected in both the Constant and UCLA scores among shoulders with and without a retear. Previous articles have also reported that clinical scores improved postoperatively, even in shoulders with a retear[3,8,19]. Clinical scores, including the Constant and UCLA scores, are usually based on various components such as pain and ROM. This may explain why these scores have been shown to improve even in shoulders with a retear. In fact, in the present study, shoulders with a retear had significantly improved ROM postoperatively in all directions except for external rotation.

This study had several limitations. First, T2 values can be affected not only by fat content but also by water content. To eliminate the influence of water content on T2 values, acute traumatic cases were excluded. Second, the external rotation strength does not represent the isolated power of the infraspinatus muscle. Other muscles, such as the teres minor and deltoid, are also involved in the external rotation of the shoulder, and it is difficult to measure the isolated power of the infraspinatus. Third, the operations were performed by multiple surgeons, including fellows and senior surgeons. This factor likely had negligible influence given that the fellows were closely supervised by senior surgeons. Lastly, abduction strength was not evaluated. We excluded this measurement because it is highly influenced by various factors, such as pain and other muscles. In fact, in some cases, we experienced difficulties in measuring preoperative abduction strength because of pain caused by subacromial impingement. Despite these limitations, the findings of this study provide reliable information that fatty degeneration of the rotator cuff muscles can be reversed following successful tendon repair.

In conclusion, shoulders with successful repair demonstrated significantly smaller T2 values and improved external rotation strength after surgery. Fatty degeneration of the rotator cuff muscles can be reversed, at least in part, and muscle strength improves in shoulders with successful repair. ■

Note: The authors thank Satoka Yamazaki for data collection and Koharu Matsuki for English-language editing.

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