



# Tendon stump type on magnetic resonance imaging is a predictive factor for retear after arthroscopic rotator cuff repair

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**Background:** Fatty infiltration of the rotator cuff musculature increases in larger tears and is a factor in re-tearing. However, tearing may recur even in patients with small original tears and little fatty infiltration of the rotator cuff musculature. We devised a system to classify the rotator cuff tendon stump by magnetic resonance imaging (MRI) signal intensity and investigated prognosis-related factors associated with retear based on other MRI findings.

**Methods:** We analyzed and compared the signal intensity of the rotator cuff tendon stump and deltoid on preoperative T2-weighted fat-suppressed MRI in 305 patients who underwent primary arthroscopic rotator cuff repair. We also investigated the tear size, Goutallier stage, and global fatty degeneration index.

**Results:** In a type 1 stump, the tendon stump had a lower (darker) signal intensity than the deltoid. In type 2, the signal intensities of the tendon stump and deltoid were equivalent. In type 3, the signal intensity of the tendon stump was higher (whiter) than that of the deltoid. Multiple regression analysis of the association between retear and other parameters identified stump type (odds ratio [OR], 4.28), global fatty degeneration index (OR, 2.99), and anteroposterior tear size (OR, 1.06) as significant factors. The retear rates were 3.4% for type 1 stumps, 4.9% for type 2, and 17.7% for type 3.

**Conclusions:** Type 3 stumps had a significantly higher retear rate, suggesting that stump signal intensity may be an important indicator for assessing the stump's condition. Our stump classification may be useful in choosing suture techniques and postoperative therapies.

**Level of evidence:** Level II; Retrospective Design; Prognosis Study

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**Keywords:** Retearing after arthroscopic rotator cuff repair; quality of rotator cuff tendon stump; MRI signal intensity of stump; predictive retearing factor; evaluation of preoperative MRI; results after arthroscopic rotator cuff repair

The substance of this study was presented at the 44th and 45th meetings of the Japan Shoulder Society in October 2017 and October 2018. The authors were very honored to receive the Excellent Abstract Award (NANIWA Award) for this study at the 45th meeting of the Japan Shoulder Society in Osaka, Japan, October 19, 2018.

The study was approved by the Health Sciences Institutional Review Board of Fukuoka Shion Hospital (approval No. 5).

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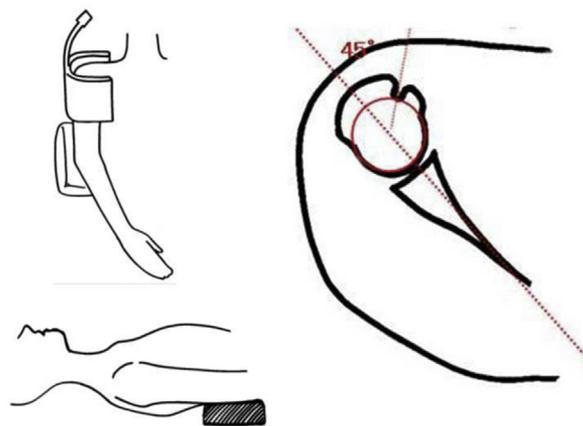
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Studies have shown that age, fatty infiltration, atrophy of the rotator cuff musculature, and tear size are among the interacting factors that contribute to re-tear of the rotator cuff tendon.<sup>1,5</sup> In the imaging evaluation of fatty infiltration, Goutallier et al<sup>4</sup> created a 5-stage scale based on computed tomography imaging. They found that re-tearing occurred in 100% of patients with a classification of stage 2 or worse and that fatty infiltration contributed to postoperative tendon congruity.<sup>5</sup> Fuchs et al<sup>3</sup> used magnetic resonance imaging (MRI) for the evaluation of the Goutallier stage, and currently, Goutallier staging based on MRI is the most commonly used modality for evaluating fatty infiltration; this method was used in our study. Because fatty infiltration of the rotator cuff musculature increases in larger tears, it is clearly a factor in re-tearing. However, tearing may recur even in patients in whom the original tear was small and there is little fatty infiltration of the rotator cuff musculature.

MRI is now essential for the imaging diagnosis of rotator cuff disorders. Complete rotator cuff tears can be diagnosed on T2-weighted imaging, but the highly sensitive visualization provided by fat saturation (SAT) is useful in cases of rotator cuff tendinitis and partial tears. In detailed observations of the rotator cuff stump after complete rotator cuff tears, the color of the stump appears whitish in some patients and black in others on fat SAT MRI, despite no clear difference being apparent on T2-weighted imaging. Because fat SAT brings out the water content of tissue, degeneration and edema also appear as hyperintensities. We hypothesized that the signal intensity of the rotator cuff stump may reflect the condition of the stump and contribute to postoperative outcomes, and we developed an assessment method (stump classification) using fat SAT MRI. Subsequently, we examined all cases after arthroscopic rotator cuff repair (ARCR) to investigate the association between stump classification and re-tearing after the repair.

## Materials and methods

The participants in this retrospective study were consecutively recruited from the Department of Orthopaedic Surgery, Fukuoka Shion Hospital, from May 2011 to April 2017. The single-center cohort in this study consisted of 305 consecutive Japanese patients who underwent primary ARCR; we sought to investigate prognosis-related factors associated with re-tear from the perspective of other MRI findings. Eligible patients were aged 20 years or older. We investigated 305 patients who were followed up for at least 1 year postoperatively. We performed MRI in all patients at 1 year after ARCR and evaluated the integrity of the tendon. The patients comprised 171 men and 134 women with a mean age of  $64.9 \pm 6.73$  years. Written consent was obtained from all participants.



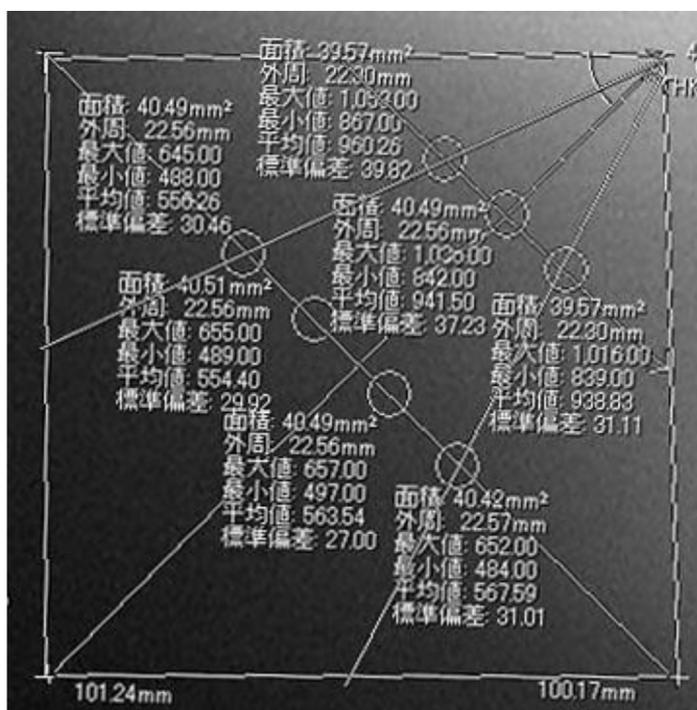
**Figure 1** Patient position for oblique coronal magnetic resonance imaging. The patient's shoulder is adjusted to achieve mild internal rotation, and the upper arm is kept parallel to the bed. We set the oblique coronal image plane parallel to a reference line joining the scapular body and center of the humeral head, and we position the arm so that the line joining the center of the humeral head and the intertubercular sulcus is at  $45^\circ$  to this reference line to ensure consistent upper arm rotation.

The repair techniques used were single-row (SR) repair in 40 patients, double-row (DR) repair in 59, and bridging suture (BS) repair in 206. Only the first author operated on all patients.

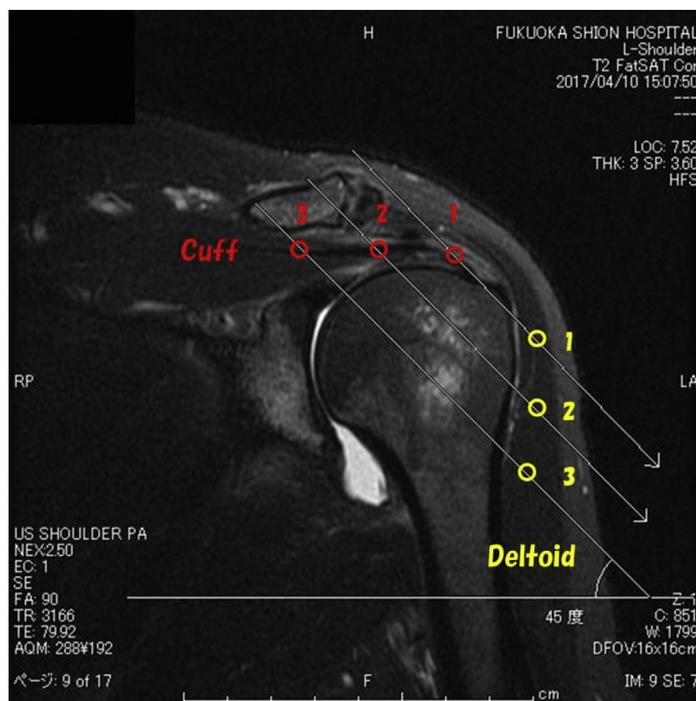
In our MRI technique, we set the oblique coronal image plane parallel to a reference line joining the scapular body and the center of the humeral head, and we positioned the arm so that the line joining the center of the humeral head and the intertubercular sulcus was at  $45^\circ$  to this reference line to ensure consistent upper arm rotation (Fig. 1). Oblique coronal images were scanned in 2 sequences, comprising spin-echo T2-weighted imaging and T2 fat SAT fat-suppressed imaging.

We first investigated the characteristics of signal intensity on MRI using a Brivo MR 355 superconducting 1.5-T system (GE Healthcare Japan, Hino, Japan). A phantom comprising a rectangular container filled with an aqueous nickel solution was fitted with a dedicated shoulder coil and imaged by spin-echo T2 fat SAT, a fat-suppressing imaging sequence, in the same plane as used for coronal imaging of the left shoulder. The signal intensity reflected the distance from the coil, declining from the top right to the bottom left of the image. When a  $45^\circ$  line was drawn from the top left to the bottom right of the image, the signal intensity at all points on this line was equivalent (Fig. 2). When this technique is applied to actual oblique coronal images of the shoulder, because the rotator cuff musculature and deltoid are part of the same muscle group and run in perpendicular directions, their signal intensities on this  $45^\circ$  line should be equivalent.

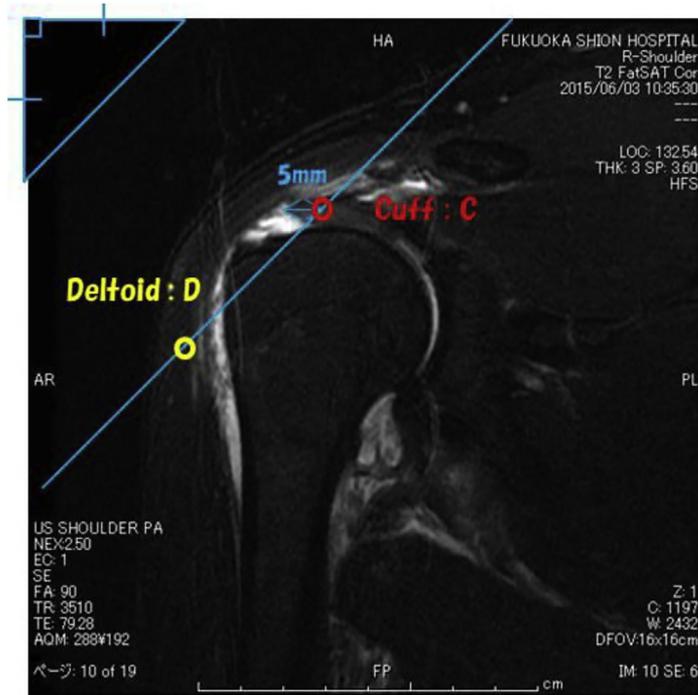
We measured the signal intensities of the rotator cuff and deltoid in 30 middle-aged individuals without rotator



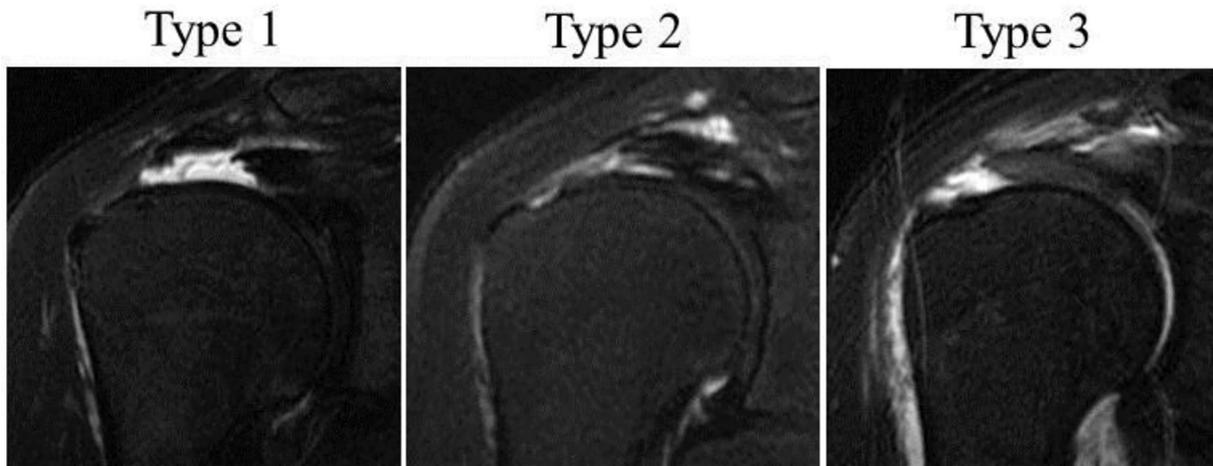
**Figure 2** Spin-echo T2 fat saturation fat-suppressed image. The signal intensity reflects the distance from the coil, declining from the *top right* to the *bottom left*.



**Figure 3** Measurement method in the oblique coronal image plane (T2 fat saturation) in a healthy shoulder. The tendon (*red 1*) and deltoid (*yellow 1*) are on a 45° line passing through the footprint. The musculotendinous junction (*red 2*) and deltoid (*yellow 2*) are on a 45° line intermediately between lines 1 and 3. The rotator cuff musculature (*red 3*) and deltoid (*yellow 3*) are on a 45° line passing through the center of the humeral head.



**Figure 4** Measurement method in the oblique coronal image plane (T2 fat saturation) in a shoulder with a rotator cuff tear. Three consecutive slices clearly visualizing the stump are used. The signal intensities are measured at a location 5 to 8 mm from the tip of the stump (*C*) and in the deltoid (*D*) on the 45° line.



**Figure 5** Stump classification. In type 1, the stump appears darker than the deltoid, with a ratio of rotator cuff stump signal intensity to deltoid signal intensity (*C/D*) less than 0.8. In type 2, the stump is similar in color to the deltoid, with a *C/D* ratio of 0.8 to 1.3. In type 3, the stump appears whiter than the deltoid, with a *C/D* ratio greater than 1.3.

cuff tears. In our MRI technique, we set the oblique coronal image plane parallel to a reference line joining the scapular body and center of the humeral head. We also positioned the patient’s arm so that the line joining the center of the humeral head and intertubercular sulcus was at 45° to this reference line to ensure consistent upper arm rotation. The horizontal plane was set perpendicular to the glenoid cavity of the scapula. The signal intensity measurement points in the oblique coronal plane passing through the center of the humeral head were in the rotator

cuff tendon and deltoid on a 45° line passing through the footprint, in the rotator cuff musculature and deltoid on a 45° line passing through the center of the humeral head, and in the musculotendinous junction and deltoid on a 45° line intermediately between those 2 lines. From the superior-lateral side of the shoulder, the measurement points in the rotator cuff tendon were designated as C1, C2, and C3 and those in the deltoid were designated as D1, D2, and D3, and the signal intensities in 10-mm<sup>2</sup> circles at these points were measured (Fig. 3).

**Table I** Results by stump type

Stump	Age, yr	Goutallier stage			GFDI	Tear size, mm		Retear rate, %
		SSP	ISP	SSC		AP	ML	
Type 1	64.0	1.7	1.0	0.5	1.10	29.1	29.2	3.4
Type 2	64.9	1.5	0.8	0.5	0.96	27.5	27.6	4.9
Type 3	65.3	1.5	0.9	0.6	1.00	27.6	27.5	17.7

SSP, supraspinatus; ISP, infraspinatus; SSC, subscapularis; GFDI, global fatty degeneration index; AP, anterior-posterior; ML, medial-lateral. The retear rate is significantly higher for type 3 than for type 2 stumps ( $P < .05$ ).

By use of the signal intensity of D1 as the reference value for the deltoid, the signal intensities at D2 and D3 decreased significantly and uniformly, with D2/D1 equal to 0.90 and D3/D1 equal to 0.80. The signal intensity decreased at a consistent rate with increasing distance from the coil. The ratio of the deltoid and rotator cuff signal intensities at C3/D3, the points at which both consisted of muscle tissue, was 1.04 (unbiased variance, 0.017; standard deviation [SD], 0.133). The signal intensities of the deltoid and rotator cuff musculature were almost equivalent, and their variance was also low. The ratio of the deltoid and rotator cuff signal intensities at C1/D1 was 0.58 (unbiased variance, 0.026; SD, 0.163). The signal intensity of the tendinous portion of the rotator cuff was significantly lower than that of the deltoid. The ratio of the deltoid and rotator cuff signal intensities at C2/D2, in the musculotendinous junction of the rotator cuff, was 0.92 (unbiased variance, 0.063; SD, 0.251).

The signal intensity ratio data for the deltoid and rotator cuff musculature exhibited low variance and a low SD and were normally distributed. The 95% confidence interval was 0.78 to 1.31, and these values were rounded to 1 decimal place to give a reference range for signal intensity of 0.8 to 1.3.

We classified the value of the rotator cuff stump signal intensity (C) divided by the deltoid signal intensity (D) in patients with actual rotator cuff tears into 3 types and defined our stump classification in terms of the C/D ratio. Measurements were made using 3 consecutive slices to clearly visualize the stump on T2 fat SAT oblique coronal images. The signal intensities were measured in a 10-mm<sup>2</sup> circle located 5 to 8 mm from the end of the stump as the medial anchor suture location and in the deltoid on the 45° line (Fig. 4), and the mean C/D value of the 3 slices was calculated. Measurement of the C/D ratio can be performed within 5 minutes. The stump was classified as type 1 if the stump appeared darker than the deltoid, with a C/D ratio less than 0.8; as type 2 if the stump was similar in color to the deltoid, with a C/D ratio of 0.8 to 1.3; and as type 3 if the stump appeared whiter than the deltoid, with a C/D ratio greater than 1.3 (Fig. 5).

We investigated the mean age of the patients, tear size, Goutallier stage (supraspinatus, infraspinatus, and subscapularis) on preoperative MRI, and global fatty

**Table II** Results of multiple logistic analysis by stepwise method

method	OR	95% CI		P value
		Lower bound	Upper bound	
AP size	1.06	1.01	1.10	<.01
GFDI	2.99	1.38	6.50	<.01
Stump type	4.28	2.02	9.06	<.01

OR, odds ratio; CI, confidence interval; AP, anterior-posterior; GFDI, global fatty degeneration index.

degeneration index (GFDI)<sup>5</sup> as indicators of fatty infiltration of the rotator cuff musculature and the Sugaya classification<sup>14</sup> (type 4 or 5 retear) as an indicator of rotator cuff stump integrity at 1 year postoperatively. Statistical analysis was performed using 1-way analysis of variance, the  $\chi^2$  test, and logistic regression analysis, with  $P < .05$  regarded as statistically significant. We used statistical software (R, version 2.8.1; R Foundation for Statistical Computing, Vienna, Austria) to analyze the data.

## Results

The stump was type 1 in 59 patients (28 men and 31 women), type 2 in 122 (64 men and 58 women), and type 3 in 124 (79 men and 45 women) (Table I). Patients' mean ages were  $64.0 \pm 7.7$  years for type 1,  $64.9 \pm 5.9$  years for type 2, and  $65.3 \pm 7.8$  years for type 3, with no significant difference among the 3 types. Tear size was  $29.1 \pm 11.4$  mm,  $27.5 \pm 12.3$  mm, and  $27.6 \pm 11.3$  mm, respectively, anteroposteriorly and  $29.2 \pm 9.6$  mm,  $27.6 \pm 10.5$  mm, and  $27.5 \pm 10.3$  mm, respectively, mediolaterally, with no significant difference for either parameter. Supraspinatus Goutallier stages were  $1.7 \pm 0.7$ ,  $1.5 \pm 0.7$ , and  $1.5 \pm 0.7$ , respectively. Infraspinatus Goutallier stages were  $1.0 \pm 0.7$ ,  $0.8 \pm 0.4$ , and  $0.9 \pm 0.7$ , respectively. Subscapularis Goutallier stages were  $0.5 \pm 0.7$ ,  $0.5 \pm 0.4$ , and  $0.6 \pm 0.8$ , respectively. GFDIs were  $1.10 \pm 0.57$ ,  $0.96 \pm 0.54$ , and  $1.00 \pm 0.57$ , respectively. No significant differences were seen among the groups for the 4 aforementioned measurements.

The overall retear rate was 9.8% (30 of 305 patients). By type, the rates were 3.4% (2 of 59 patients) for type 1

stumps, 4.9% (6 of 122 patients) for type 2, and 17.7% (22 of 124 patients) for type 3. Retearing was significantly more common in type 3 than in type 1 or 2 ( $P < .05$ ). The repair technique used was SR repair in 40 patients, DR repair in 59, and BS repair in 206, and the numbers of retears were 7 with SR repair, 6 with DR repair, and 17 with BS repair. No significant difference was found among the repair techniques.

To investigate factors associated with retearing, we conducted multiple logistic regression analysis by the stepwise method with retearing as the target variable and other parameters as explanatory variables. This analysis showed that anteroposterior tear size, GFDI, and stump type were significant factors ( $P < .01$ , model  $\chi^2$  test). The odds ratios were 1.06 for anteroposterior tear size, 2.99 for GFDI, and 4.28 for stump type (Table II). These findings suggested that stump type was the factor most strongly associated with retearing.

## Discussion

In this study, we devised our own stump classification system for grading the condition (quality) of tendon stumps on MRI images. In a type 1 stump, the tendon stump had a lower (darker) signal intensity than the deltoid. In type 2, the signal intensities of the tendon stump and deltoid were equivalent. In type 3, the signal intensity of the tendon stump was higher (whiter) than that of the deltoid. Our study showed that type 3 stumps had a significantly higher re-tear rate than type 1 or 2 stumps, which suggested that stump signal intensity may be an important indicator for assessing the stump's condition. To our knowledge, this is the first study to show that our stump classification may be useful in assessing the preoperative condition of tendon stumps.

ARCR using suture anchoring now achieves stable outcomes. Biomechanical studies have revealed the characteristics of the SR, DR, and BS techniques,<sup>11</sup> and the DR technique (which provides a larger contact area at the footprint site than the SR technique) and BS technique (which also provides strong contact pressure) are now widely used. Even with the use of these techniques, however, retearing may still occur. The cause of retearing may be a mechanical or biological failure. In the DR and BS techniques, stress is known to be concentrated in the medial-row anchors, and failure of the medial row (type 2 failure) has been reported.<sup>7</sup> Biomechanical studies have also shown that failure of the medial-row anchors increases if the sutures are placed in the musculotendinous junction rather than in the tendon parenchyma.<sup>15</sup> In practice, the tendon tends to rupture near the medial footprint, leaving little tendon parenchyma in the stump, which means that the sutures must be placed in the musculotendinous junction. In patients with a stump measuring less than 10 mm, the DR technique reportedly has a higher rate of retearing

than the SR technique,<sup>8</sup> and the condition (quality) of the tendon stump at the anchor placement location may be closely associated with retearing. We supposed that the tendon stump length was related to retearing as tendon stump type. However, it was difficult to judge the tendon stump length by MRI.

With respect to MRI evaluation of the tendon stump, Sein et al<sup>13</sup> graded supraspinatus tendinopathy on MRI and reported that tendons with a higher signal intensity were in a more severe condition. Studies of cadaveric shoulders have shown that histologic degeneration of the tendon increases signal intensity<sup>12</sup> and that sites of higher signal intensity on T2-weighted imaging are associated with severe histologic degeneration of the tendon.<sup>9</sup> In a histopathologic study, Hashimoto et al<sup>6</sup> reported that although there were no inflammatory signs in the tendon stump, there were widespread degenerative changes in the middle and deep layers of the tendon. In our study, progression in stump type (a higher signal intensity ratio) was strongly correlated with the pathologic condition of the stump, mainly degeneration, suggesting that it may be possible to evaluate the stump's condition and quality based on MRI findings.

Few previous studies have focused on factors in retearing after rotator cuff repair. Chung et al<sup>2</sup> reported that, in partial-thickness and small full-thickness rotator cuff tears, the re-tear rate was higher for patients in whom the tendon had a high signal intensity on MRI than for those in whom the signal intensity was low. In a study by Li et al<sup>10</sup> determining the maturity of the repaired tendon by tendon signal intensity on postoperative MRI, a high signal intensity suggested that the quality of the repaired tendon was poor. In our study, patients with a rotator cuff tendon stump with a high signal intensity ratio after complete tendon rupture (type 3 stump) had a significantly higher re-tear rate. Because healthy tendon has a lower signal intensity than muscle, it is likely that type 1 stumps, which have a lower signal intensity than the deltoid muscle, are closer to a healthy state and that the condition (quality) of type 3 stumps, which have a higher signal intensity, may have become degraded. The results of multiple logistic regression analysis of patients with type 3 stumps, which had a higher re-tear rate, suggested that the signal intensity of the stump may be an important indicator. The absence of any significant difference in GFDI between the different stump types means that no direct association between the signal intensity of the stump and fatty infiltration of the rotator cuff musculature has been demonstrated.

This study had numerous limitations. First, only the first author performed the described measurements, and no interobserver or intraobserver reliability testing was performed. Second, there was variation in the time from injury to MRI, and the effect of the presence of intra-articular inflammation and edema on stump signal intensity is unknown. Third, we could not examine diabetes, smoking, and so on as patient risk factors. Finally, even when the

same sequences are used, MRI settings vary between devices and institutions, and differences in the color of the stump may not always be evident. Although it is unknown whether the results of our study would be replicated in other institutions, evaluating the signal intensity of the rotator cuff tendon stump on preoperative fat SAT fat-suppressed MRI scans may be important for selecting the most appropriate surgical technique and predicting postoperative outcomes. In the future, we plan to investigate the association between stump pathology and stump classification and would like to investigate the factors that affect the occurrence of type 3 stumps. Our stump classification, which enables the condition of the stump to be assessed at a glance in terms of its signal intensity (color), may be useful for this purpose.

## Conclusion

We used preoperative MRI (T2 fat SAT fat-suppressed imaging) of the rotator cuff tendon stump in patients with rotator cuff tears to define our stump type classification in terms of the stump signal intensity. Of the parameters investigated in this study, stump type, which indicates the condition of the stump, was the factor most strongly associated with retearing. Type 3 stumps, which have a higher signal intensity than the deltoid, had a significantly higher retear rate. This finding suggests that stump signal intensity may be an important indicator for assessing the condition of the stump. Our stump classification may also be useful in choosing suture techniques and postoperative therapies.

## Acknowledgments

The authors thank Akihiko Inoue, Manabu Oura, Tada-shi Yanaga, Youta Takagi, Takuma Nozaki, and Daisuke Tatara from our department for assistance with data collection. They also thank Editage ([www.editage.jp](http://www.editage.jp)) for English-language editing.

## Disclaimer

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