Quantitative evaluation of fatty degeneration of the supraspinatus and infraspinatus muscles using T2 mapping

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Background: Although fatty degeneration of the rotator cuff muscles has been reported to affect the outcomes of rotator cuff repairs, only a few studies have attempted to quantitatively evaluate this degeneration. T2 mapping is a quantitative magnetic resonance imaging technique that potentially evaluates the concentration of fat in muscles. The purpose of this study was to investigate fatty degeneration of the rotator cuff muscles by using T2 mapping, as well as to evaluate the reliability of T2 measurement.

Methods: We obtained magnetic resonance images including T2 mapping from 184 shoulders (180 patients; 110 male patients [112 shoulders] and 70 female patients [72 shoulders]; mean age, 62 years [range, 16-84 years]). Eighty-three shoulders had no rotator cuff tear (group A), whereas 101 shoulders had tears, of which 62 were incomplete to medium (group B) and 39 were large to massive (group C). T2 values of the supraspinatus and infraspinatus muscles were measured and compared among groups. Intraobserver and interobserver variabilities also were examined.

Results: The mean T2 values of the supraspinatus in groups A, B, and C were 36.3 ± 4.7 milliseconds, 44.2 ± 11.3 milliseconds, and 57.0 ± 18.8 milliseconds, respectively. The mean T2 values of the infraspinatus in groups A, B, and C were 36.1 ± 5.1 milliseconds, 40.0 ± 11.1 milliseconds, and 51.9 ± 18.2 milliseconds, respectively. The T2 value significantly increased with the extent of the tear in both muscles. Both intraobserver and interobserver variabilities were more than 0.99.

Conclusion: T2 mapping can be a reliable tool to quantify fatty degeneration of the rotator cuff muscles.


Keywords: Shoulder; rotator cuff tear; supraspinatus; infraspinatus; fatty degeneration; magnetic resonance imaging; T2 mapping

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Rotator cuff tears are among the most common injuries of the shoulder. After a tear of its tendon, the musculotendinous unit retracts permanently, undergoes atrophy
and fatty infiltration, and loses elasticity. Even after successful rotator cuff repair, these muscle changes have been recognized to be irreversible.

In studies using computed tomography or magnetic resonance imaging (MRI), fatty degeneration of rotator cuff muscles has been reported to affect the outcome of both open and arthroscopic rotator cuff repairs. Semiquantitative methods, such as Goutallier staging, commonly have been used for evaluation of fatty degeneration of rotator cuff muscles; however, quantitative methods have been described in only a few published articles.

T2 mapping is an MRI technique that can evaluate objects quantitatively and has been mainly used for quantitative evaluation of articular cartilage in musculoskeletal imaging. This technique can be applied for quantitative assessment of fatty degeneration of muscles. Several published articles have evaluated fatty degeneration of muscles in muscular dystrophy. They concluded that T2 mapping could be used to characterize muscle composition and evaluate function.

We have already reported a preliminary study that evaluated fatty degeneration of rotator cuff muscles using the T2 mapping technique. In that study, we found that T2 values of cuff muscles showed little change with age but they increased in proportion to the size of rotator cuff tears. Therefore, in that report, we suggested that T2 mapping might be a useful method for quantitative evaluation of fatty degeneration of the cuff muscles. However, we had examined only a small number of patients, and this was the largest limitation of our study. In addition, we did not evaluate the reliability of T2 measurement in that report. Consequently, in the present study, we planned to measure the T2 values of the rotator cuff muscles in a large number of patients with or without rotator cuff tears by using the T2 mapping technique and to compare these values among patient groups that were divided according to tear size. In addition, we examined the relationship between T2 assessments and Goutallier staging. We also determined intraobserver and interobserver variabilities of T2 measurement. We hypothesized that larger tears would show significantly longer T2 values in a larger patient population, just as had been shown in the previous study, and that T2 measurement would show high reliability.

Materials and methods

Patients

We retrospectively reviewed patients’ records and radiographic images, and between January 2008 and September 2012, MRI was performed on 211 shoulders in 204 patients and included T2 mapping because of suspected rotator cuff tears. Cases involving trauma within the previous month (8 shoulders) or those associated with neuromuscular diseases (8 shoulders), arthritic diseases (6 shoulders), isolated tears of the subscapularis tendon (4 shoulders), and tumor in the shoulder girdle (1 shoulder) were excluded from the study. Thus, 184 shoulders in 180 patients were finally included in this study. The patients consisted of 110 male patients (112 shoulders) and 70 female patients (72 shoulders) with a mean age of 62 years (range, 16-84 years).

MRI acquisition

A 1.5-T MRI system (Signa HDx; GE Healthcare, Milwaukee, WI, USA) was used in all patients, and T2 mapping was performed in addition to routine, diagnostic T1- and T2-weighted imaging. T2 measurement with single-slice acquisition was performed on the most lateral of the oblique sagittal images in which the scapular spine remained in contact with the scapular body by use of a multi–spin-echo sequence. The multi–spin-echo scanning parameters were as follows: 8 echo times of 11 to 88 milliseconds; repetition time, 1,500 milliseconds; field of view, 200 × 200 mm; matrix size, 320 × 320; and slice thickness, 5.0 mm.

T2 measurement

For T2 measurements, T2-calculated maps were generated by use of MATLAB software (The MathWorks, Natick, MA, USA) with a monoexponential curve fit. The region of interest (ROI) was drawn manually on the border of the supraspinatus (SSP) and the infraspinatus (ISP) on T2-weighted images of the same slices as the images on which T2 measurement was performed by use of image processing software (ImageJ; National Institutes of Health, Bethesda, MD, USA) by a single experienced shoulder surgeon, and the ROIs were then copied and pasted onto the T2-calculated maps. Thus, average T2 values of the SSP and ISP muscles were measured (Fig. 1). Color-coded T2-calculated maps were created by use of MATLAB software for visualization (Fig. 2). Degenerated muscles would show a long T2 value, reflecting increased fat content.

Radiologic diagnosis

Radiologic diagnosis was made by radiologists, and the size of the rotator cuff tears was determined based on a previously published article: incomplete tear (both articular and bursal side), small tear (<1 cm in the coronal plane), medium tear (<3 cm), large tear (<5 cm), or massive tear (>5 cm). The patients were divided into 3 groups according to rotator cuff tear size. Eighty-three shoulders had no rotator cuff tear (group A), and 101 shoulders had rotator cuff tears; of the latter, 62 had incomplete to medium tears (group B) and 39 had large to massive tears (group C). The clinical diagnoses of the shoulders without tears were impingement syndrome (51 shoulders), frozen shoulder (24 shoulders), rotator cuff tendinitis (4 shoulders), tendinitis of the long head of the biceps brachii (2 shoulders), and osteoarthritis of the acromioclavicular joint (2 shoulders). Goutallier staging of the SSP and ISP was evaluated on the same slice as T2 measurement as follows: stage 0, no fatty infiltration; stage 1, some fatty streaks; stage 2, less fat than muscle; stage 3, as much fat as muscle; or stage 4, more fat than muscle.
T2 values of the SSP and ISP muscles were compared among the groups. The relationship between T2 assessments and Goutallier staging was also examined. One-way analysis of variance and the Tukey post hoc test were used for statistical analysis, and the level of significance was set at $P < .05$. One-way analysis of variance and the post hoc test were also used for comparison of age and duration of symptoms among the groups. The Kruskal-Wallis test and a post hoc test were used for comparison of the other demographic data, such as gender. Pearson correlation was used to examine the relationship between T2 value and age, as well as between T2 value and duration of symptoms, in the shoulders with rotator cuff tears. All analyses were performed with commercial software (PASW, version 17.0; SPSS, Chicago, IL, USA).

To investigate intraobserver and interobserver variability of T2 measurement, we used images from 20 randomly selected patients. We measured the area of the SSP and ISP to analyze the preciseness of manual drawing of the ROI, as well as T2 values. For intraobserver variability, a single author evaluated the images 3 times at 1-week intervals, and the intraclass correlation coefficient [ICC(1,1)] was determined. For interobserver variability, 2 authors evaluated the images independently, and ICC(2,1) was determined.

Power analysis for detection of differences among the groups was conducted by use of an $z$ value of .05; an effect size of 0.4, which was determined according to the results of the preliminary study; and a power of 0.95. Power analysis suggested that 34 patients were needed for each group. Thus, the patients for this study were collected until all groups had at least 34 patients.

**Results**

Patient demographic data are summarized in Table I. There were no significant intergroup differences in gender and duration of symptoms. Patients in group A were younger and had a smaller incidence of traumatic events than those in groups B and C.

The mean T2 values of the SSP in groups A, B, and C were $36.3 \pm 4.7$ milliseconds, $44.2 \pm 11.3$ milliseconds, and $57.0 \pm 18.8$ milliseconds, respectively (Fig. 3, A), and the intergroup differences were statistically significant ($P < .001$). The post hoc test also showed significant intergroup differences.

The mean T2 values of the ISP in groups A, B, and C were $36.1 \pm 5.1$ milliseconds, $40.0 \pm 11.1$ milliseconds, and $51.9 \pm 18.2$ milliseconds, respectively (Fig. 3, B), and the difference among the groups was statistically significant ($P < .001$). There were significant differences between groups A and C and groups B and C with the post hoc test.

According to Goutallier staging, 46 muscles were graded as stage 0; 115 muscles, stage 1; 164 muscles, stage 2; 25 muscles, stage 3; and 18 muscles, stage 4. The muscles with the higher Goutallier stages showed significantly longer T2 values ($P < .001$) (Fig. 4). The post hoc test showed significant differences between all pairs of stages, except between stages 0 and 1. The higher stages showed a tendency to have larger standard deviations compared with the lower stages.

There were no significant correlations between age and T2 value in both the SSP and ISP ($r = 0.09$ and $r = 0.18$, respectively).
There was also no significant correlation between the duration of symptoms and T2 value in either muscle ($r = 0.09$ and $r = 0.08$, respectively).

Intraobserver reliabilities for T2 of the SSP, SSP area, T2 of the ISP, and ISP area were 0.994, 0.984, 0.996, and 0.959, respectively. Interobserver reliabilities for T2 of the SSP, SSP area, T2 of the ISP, and ISP area were 0.994, 0.980, 0.994, and 0.987, respectively.

### Discussion

Fatty degeneration of the rotator cuff muscles is an important factor that affects shoulder function, reparability of rotator cuff tears, and the outcomes of rotator cuff repairs.\(^2,4,5,11,16,22,27\) However, most studies have used semi-quantitative evaluation of fatty degeneration, such as Goutallier staging. Recently, a few MRI studies that quantitatively evaluated fatty degeneration were reported.\(^9,18,24,28\) Kenn et al.\(^9\) studied shoulders with rotator cuff tears using magnetic resonance spectroscopy and concluded that it allowed exact quantification of fatty degeneration. Samagh et al.\(^20\) used mouse models of rotator cuff tears and showed that MRI quantification had a high correlation with fat levels measured by use of histologic examinations and a triglyceride quantification assay. We reported a preliminary study that evaluated fatty degeneration of the SSP and ISP by using T2 mapping with a small number of patients.\(^13\) The T2 mapping technique is an established method to quantify fatty degeneration of muscles in muscular dystrophy.\(^7,9,19\) Fat deposition and restricted motion of the water molecules, which is affected by loss of muscle protein and replacement with different macromolecules such as fat, can increase the T2 value of the degenerated muscle.\(^7,9\)

This study showed that T2 values of the SSP and ISP significantly increase with the extent of rotator cuff tear, and the results matched our hypothesis. Smaller tears (group B) had significantly longer T2 values than shoulders without tears (group A) in the SSP; however, there was no difference between the two groups in the ISP. Rotator cuff tears usually initiate at the anterosuperior portion of the SSP and extend posteriorly. Smaller tears might not show a significant increase in T2 values because they would involve the ISP less extensively than do larger tears.

The degree of fatty degeneration was not affected by patients’ age and duration of symptoms. It is thought that...
fatty degeneration of the rotator cuff muscles progresses after tendon tears.\textsuperscript{14,15} However, it is well known that asymptomatic rotator cuff tears exist,\textsuperscript{8,26} and the appearance of symptoms does not necessarily correspond with the initiation of the tears. This may be the largest reason for the lack of correlation between T2 values and the duration of symptoms. The progression of fatty degeneration might be multifactorial. The T2 values significantly increased with the progression of the Goutallier stage; however, the standard deviations in the higher stages were larger than those in the lower stages. This may be because Goutallier staging is a semiquantitative method that divides fatty degeneration into 5 stages, and one stage can contain muscles with various degrees of fatty degeneration. In other words, it may be difficult for semiquantitative methods such as Goutallier staging to detect small differences in fatty degeneration within a stage. Many studies have concluded that fatty degeneration of the cuff muscles did not improve even after successful rotator cuff repairs.\textsuperscript{2,4,5,11,16} However, these studies were based on semiquantitative evaluation and might have overlooked improvement in fatty degeneration after rotator cuff repairs. Besides, Lippe et al\textsuperscript{12} reported that Goutallier staging did not have high interobserver reproducibility, and this might be another factor. In contrast, we showed that T2 measurement in our study had high intraobserver and interobserver variabilities. Our study suggests that the T2 mapping technique can be a reliable tool to assess fatty degeneration of the rotator cuff muscles quantitatively. This technique may have the potential to detect small changes in fatty degeneration and to elucidate improvement after rotator cuff repairs. This technique can also be used for preoperative prediction of the reparability of rotator cuff tears by assessing the relationship between reparability and T2 values. Our next step will be to conduct studies to investigate these issues, and the results of this study will be the basis for future studies. The T2 mapping technique can be used routinely for evaluation of fatty degeneration because it can be performed with clinically used MRI systems and does not require any special settings.

There were several limitations in this study. First, we did not evaluate healthy shoulders as a control. Instead, we used shoulders that were symptomatic but did not have rotator cuff tears because it was difficult to obtain magnetic resonance images of a large number of normal volunteers. In comparison with asymptomatic persons, patients with shoulder symptoms but no rotator cuff tears might have shown some differences in the rotator cuff muscles; however, we believe that the differences in T2 values between group A and normal shoulders would be small because the diversity of T2 values in group A was small enough. Second, group A showed the greatest differences in age and the highest incidence of traumatic events compared with the other groups. These differences were relatively small and might not have had much effect on the results of the study. Third, we did not measure T2 values of the subscapularis and teres minor muscles. Changes in these muscles might have some influence on the SSP and ISP. Fourth, we did not take the body sizes of the patients into account. Because this was a retrospective study, it was difficult to examine height, weight, or body mass index in all the patients. Body size might have some influence on fat content of the muscles and tear sizes; however, this may have little effect on the results because the T2 values in shoulders without tears were in a very small range. Finally, there was no reference to confirm the accuracy of our technique. For example, we have not performed basic research to examine the relationship between T2 values and fat content. However, studies in muscular dystrophy have shown that T2 values can accurately reflect fat content in muscles.\textsuperscript{7,19} In addition, we could show superiority over Goutallier staging, at least in terms of high reliability. Despite the aforementioned limitations, we believe that T2 mapping can be a reliable option to evaluate fatty degeneration of the rotator cuff muscles quantitatively.

\textbf{Conclusions}

T2 values of rotator cuff muscles increased with the extent of rotator cuff tears. Higher Goutallier stages were associated with longer T2 values. T2 measurement showed high intraobserver and interobserver variabilities. T2 mapping can be a reliable method for the quantitative evaluation of fatty degeneration in rotator cuff muscles.

\textbf{Disclaimer}

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References


