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Quantitative T2 Mapping of Articular Cartilage of the Glenohumeral Joint at 3.0T in Rotator Cuff Disease Patients: the Evaluation of Degenerative Change of Cartilage

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Original Article

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Purpose: The aim of this study is to evaluate the T2 value of the articular cartilage of the glenohumeral joint in rotator cuff disease displayed on 3.0T MRI and to apply it in clinical practice.

Materials and Methods: This study involved sixty-two patients who underwent shoulder MRI containing T2 mapping. The mean T2 value was measured by placing a free hand ROI over the glenoid or humeral cartilage from the bone-cartilage interface to the articular surface on three consecutive, oblique coronal images. The drawn ROI was subsequently divided into superior and inferior segments. The assessed mean T2 values of the articular cartilage of the glenohumeral joint were compared and evaluated based on the degree of rotator cuff tear, the degree of fatty atrophy of the rotator cuff, and the acromiohumeral distance.

Results: ICC values between two readers indicated moderate or good reproducibility. The mean T2 value for the articular cartilage of the glenoid and humeral head cartilage failed to show any significant difference based on the degree of rotator cuff tear. However, the mean T2 values of articular cartilage, based on fatty atrophy, tended to be higher in fatty atrophy 3 or fatty atrophy 4 groups while some sub-regions displayed significantly higher mean T2 values. There was no correlation between the acromiohumeral distance and the mean T2 values of the articular cartilage of the glenoid and humeral head.

Conclusion: T2 mapping of the glenohumeral joint failed to show any significant difference in quantitative analysis of the degenerative change of the articular cartilage based on the degree of rotator cuff tear. However, it also offers quantitative information on the degenerative change of cartilage of the glenohumeral joint in patients with rotator cuff tear and severe fatty atrophy of the rotator cuff.

Keywords: Shoulder; Glenohumeral; Cartilage; Rotator cuff; T2 mapping

INTRODUCTION

Rotator cuff disease mainly occurs in patients with shoulder pain, and the cases tend to becomes more pronounced in elderly patients. Over time, the partial thickness

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tear of the rotator cuff develops into a full thickness tear and eventually leads to degenerative alteration of the glenohumeral joint (1). Particularly for severe glenohumeral osteoarthritis, a more invasive surgical option such as total shoulder arthroplasty (TSA) may be considered (2). It has been reported that the re-tear rate of a restored rotator cuff tendon increases in patients with rotator cuff tear associated with early osteoarthritis (3). Consequently, early detection and frequent monitoring of osteoarthritis and degeneration of articular cartilage of the glenohumeral joint in patients with rotator cuff disease is important.

However, cartilage imaging that use conventional MR imaging have been developed with the aim of improving morphological detection of cartilage was albeit with a limitation of the ability to detect or monitor the cartilage degeneration mentioned above (4, 5). Of late, compositional MR imaging of the cartilage such as T2 and T1rho mapping technique, and dGEMRIC (delayed gadolinium-enhanced MR imaging of cartilage) techniques were included in the MR protocol of clinical trials. Among these MR techniques, the T2 mapping technique showed remarkable clinical application and numerous studies have been done on patients with knee joint complications (6-9). Therefore, we hope to use the T2 mapping technique to assess the morphological and biochemical properties of the articular cartilage of the glenohumeral joint. The aim of this study is to evaluate the T2 value of the articular cartilage of the glenohumeral joint in patients with rotator cuff disease at 3.0T and to apply it in clinical practice.

MATERIALS AND METHODS

This retrospective study was approved by our institutional review board and informed consent was waived.

Patient Selection

From February 2016 to November 2016, we retrospectively reviewed patients' medical records, MR images, and plain radiographs. 67 patients had MRI performed on their shoulders in addition to T2 mapping. The patients had reported to the hospital with shoulder pain. Of these patients, five were excluded from previous surgery and trauma. In one of the patients, both shoulders underwent MRI scans. A total of 62 patients (mean age, 59.1 years; age range, 22-77 years) were enrolled for this study, including 26 men and 36 women, and 63 shoulder MR images (right shoulder, 40; left shoulder, 23) were included in this study.
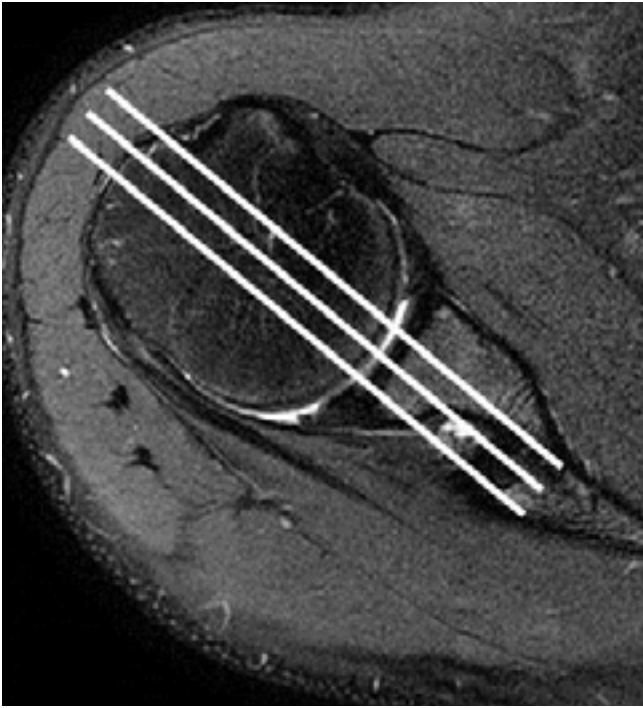
MRI Acquisition

All MR images were obtained using Magnetom Skyra (Siemens, Erlangen, Germany) and Achieva (Philips Medical Systems, Best, The Netherlands) 3.0T MRI scanners based on routine diagnostic T1 and T2-weighted imaging, and extra T2 mapping was included. The imaging sequence for T2 mapping consisted of an oblique-coronal, multi-echo spin-echo T2-weighted sequence done with the following imaging parameters: Siemens Skyra (36 shoulders, repetition time [ms], 1140; echo time [ms], 13.8, 27.6, 41.4, 55.2, 69.0; field of view [FOV] [mm], 140 × 140; matrix size, 320 × 320; voxel size [mm], 0.44 × 0.44 × 3.00; slice thickness [mm] 3.0; inter-slice gap [mm], 0.3; examination time(s), 290); Philips Achieva (27 shoulders, repetition time [ms], 2179; echo time [ms], 13.8, 27.6, 41.4, 55.2, 69.0; FOV [mm], 140 × 140; matrix size, 320 × 317; voxel size [mm], 0.44 × 0.44 × 3.00; slice thickness [mm], 3.0; inter-slice gap [mm], 0.3; examination time(s), 599).

### T2 Value Measurement and Image Analysis

The T2 maps were quantitatively evaluated by two radiologists (K.R.L, with six years of experience in musculoskeletal imaging and S.Y.K who has eight years of experience in general imaging). The T2 value was evaluated based on color-coded T2 maps comparing the T2-weighted, and oblique coronal images to obtain an accurate ROI on targeted cartilage of the glenoid and humeral head. For precise analysis of the T2 value, the three consecutive sections containing large area of humeral and glenoid cartilage were selected among the images (Fig. 1a, b). The mean T2 value was obtained by placing a free-hand region of interest (ROI) over the glenoid and humeral head cartilage from the bone-cartilage interface to the articular surface (Fig. 1c, d). The drawn ROI was ultimately divided into superior and an inferior segment by the Philips IntelliSpace Portal (ISP) 7.0. Hence, the three ROIs placed on the three consecutive sections were divided into six sub-regions i.e., anterosuperior (AS), anteroinferior (AI), middle-superior (MS), middle-inferior (MI), posterosuperior (PS), posteroinferior (PI) segments, and six T2 values were obtained from the glenoid or humeral head of one shoulder MR image. Thus, T2 value measurements were performed in both the glenoid cartilage and humeral head cartilage, respectively.

Routine diagnostic MR images were utilized to assess the degree of rotator cuff tear, i.e. (grade 1 - normal or tendinosis; grade 2 - partial thickness tear; grade 3 - full thickness tear) and the degree of fatty degeneration of the

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a

b

c


d

Fig. 1. T2 value measurement (a, b). Three consecutive oblique coronal sections comprising large areas of humeral and glenoid cartilage were selected from the images. (c, d) On color-coded T2 maps comparing the T2-weighted image. ROI was drawn on targeted cartilage of the glenoid and humeral head respectively. The drawn ROI was subsequently divided into superior and inferior segments.
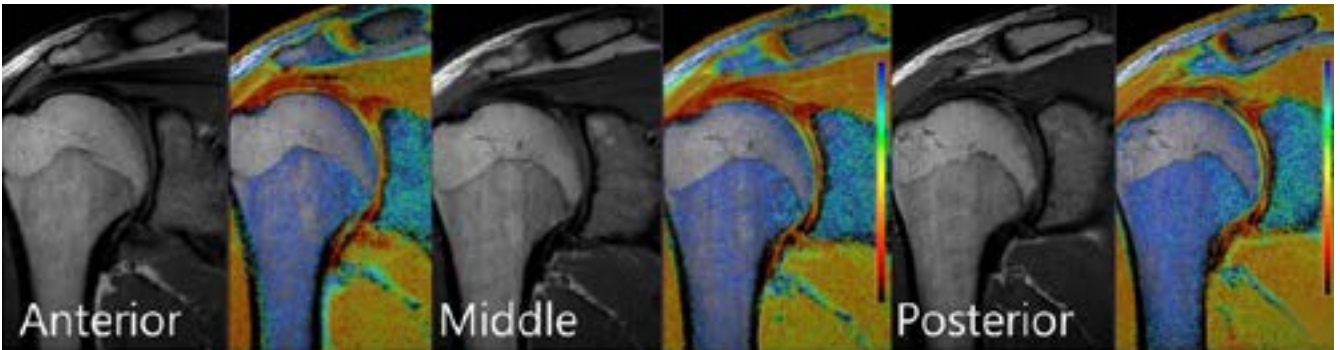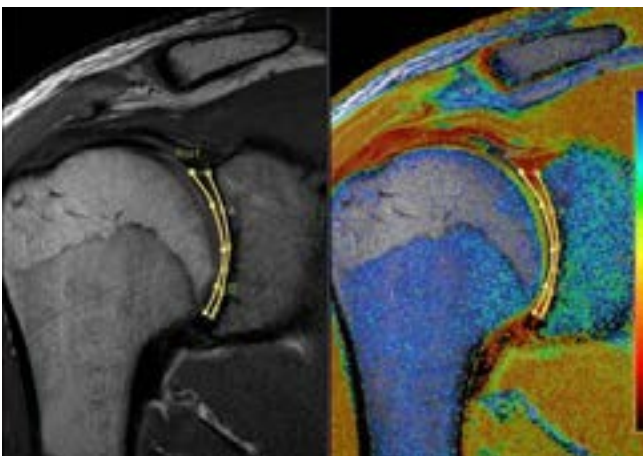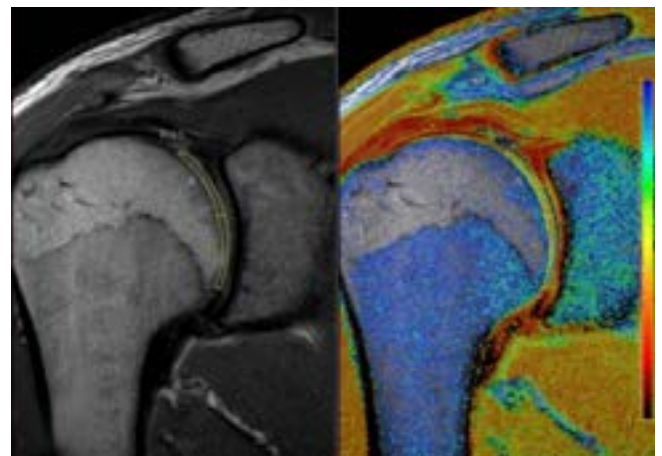
supraspinatus muscle based on the Goutallier classification i.e. (grade 0 - normal muscle; grade 1 - some fatty streaks; grade 2 - fatty muscle atrophy less than 50%; grade 3 - 50% fatty muscle atrophy; grade 4, fatty muscle atrophy greater than 50%) through consensus by the two radiologists. Additionally, the acromiohumeral distance was measured on the shoulder AP after consensus by the two radiologists.

Statistical Analysis

For comparison of the mean T2 values of the cartilage of the glenoid and humeral head among the groups classified based on the degree of rotator cuff tear, and fatty degeneration of the supraspinatus muscle, we applied the one-way analysis of variance (abbreviated one-way ANOVA). Regression analysis was used for correlation between the mean T2 values of the cartilage of the glenoid and humeral head, and acromiohumeral distance (AHD). To determine the interobserver reproducibility in the measurements of mean T2 values between reader 1 and reader 2, the intraclass correlation coefficient (ICC) with two-way mixed model of absolute agreement was used. In this study, we measured ICC values to determine the reproducibility of measured mean T2 values of all sub-regions (AS + AI + MS + MI + PS + PI) from reader 1 and reader 2. Values of ICC < 0.50 indicate poor reproducibility, those within the range of 0.50-0.75 indicate moderate reproducibility, those ranging from 0.75-0.90 indicate good reproducibility, and those >

0.90 indicate excellent reproducibility (10). All statistical analyses were performed using SPSS software version 18.0 (SPSS Inc., Chicago, IL, USA). For all statistical tests, a P value less than 0.05 was considered significant.

RESULTS

Evaluation of the ICC values for interobserver reproducibility for both measurements of articular cartilage of mean T2 values of all sub-regions (AS + AI + MS + MI + PS + PI) from reader 1 and reader 2 exhibited moderate reproducibility (ICC = 0.501) in the glenoid of glenohumeral joint and good reproducibility (ICC = 0.721) in the humeral head of glenohumeral joint (Table 1).

The mean T2 values of articular cartilage of all sub-regions of the glenoid and humeral head based on the degree of the rotator cuff tear and the degree of fatty atrophy of the supraspinatus muscle were described in Tables 2 and 3. There was no significance in the mean T2 values of articular cartilage of all sub-regions of the glenoid

Table 1. Intraclass Correlation Coefficient (ICC) for Interobserver Reproducibility between Reader 1 and Reader 2

	T2 mapping	P value
ICC of two readers (glenoid)	0.501 (0.175-0.698)	< 0.05
ICC of two readers (humeral head)	0.721 (0.538-0.831)	< 0.05

Table 2. The Mean T2 Values (ms) of Articular Cartilage of All Sub-regions of the Glenoid and Humeral Head According to the Degree of Rotator Cuff Tear for Reader 1 and Reader 2

			All sub-regions		F ratio	P value
			Mean	Sd		
Reader 1	Glenoid	Grade 1 (n = 20)	45.82	9.80	0.526	0.594
		Grade 2 (n = 21)	44.02	13.32		
		Grade 3 (n = 22)	48.38	17.50		
	Humeral head	Grade 1 (n = 20)	56.32	18.05	2.217	0.118
		Grade 2 (n = 21)	47.67	6.72		
		Grade 3 (n = 22)	55.27	16.17		
Reader 2	Glenoid	Grade 1 (n = 20)	45.80	17.36	0.038	0.963
		Grade 2 (n = 21)	45.37	15.34		
		Grade 3 (n = 22)	44.56	11.38		
	Humeral head	Grade 1 (n = 20)	49.68	9.51	1.416	0.251
		Grade 2 (n = 21)	45.42	5.85		
		Grade 3 (n = 22)	48.84	9.95		

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and humeral head based on the degree of the rotator cuff tear (Fig. 2). The mean T2 values of articular cartilage of all sub-regions of the glenoid and humeral head, based on fatty atrophy, was highest in the fatty atrophy 3 group compared to the rest of the groups in both the glenoid and humeral head cartilage for both reader 1 and reader 2 (Fig. 3). However, there was a significant difference in the glenoid cartilage according to reader 1 while there was

Table 3. The Mean T2 Values (ms) of Articular Cartilage of All Sub-regions of the Glenoid and Humeral Head According to the Degree of Fatty Atrophy of Supraspinatus for Reader 1 and Reader 2

| | | All sub-regions | | F ratio | P value |
		Mean	Sd		
Reader 1	Glenoid	Goutallier grade 1 (n = 8)	46.85	13.25	3.364	0.024
		Goutallier grade 2 (n = 48)	44.17	11.09		
		Goutallier grade 3 (n = 3)	68.15	29.71		
		Goutallier grade 4 (n = 4)	51.43	22.25		
	Humeral head	Goutallier grade 1 (n = 8)	57.13	21.98	2.072	0.114
		Goutallier grade 2 (n = 48)	50.75	10.99		
		Goutallier grade 3 (n = 3)	64.66	18.43		
		Goutallier grade 4 (n = 4)	64.19	28.82		
Reader 2	Glenoid	Goutallier grade 1 (n = 8)	42.30	11.28	0.503	0.682
		Goutallier grade 2 (n = 48)	45.40	15.64		
		Goutallier grade 3 (n = 3)	53.92	13.25		
		Goutallier grade 4 (n = 4)	42.41	5.77		
	Humeral head	Goutallier grade 1 (n = 8)	47.68	7.00	2.645	0.057
		Goutallier grade 2 (n = 48)	47.46	8.25		
		Goutallier grade 3 (n = 3)	60.97	15.83		
		Goutallier grade 4 (n = 4)	44.98	5.51		

a   b
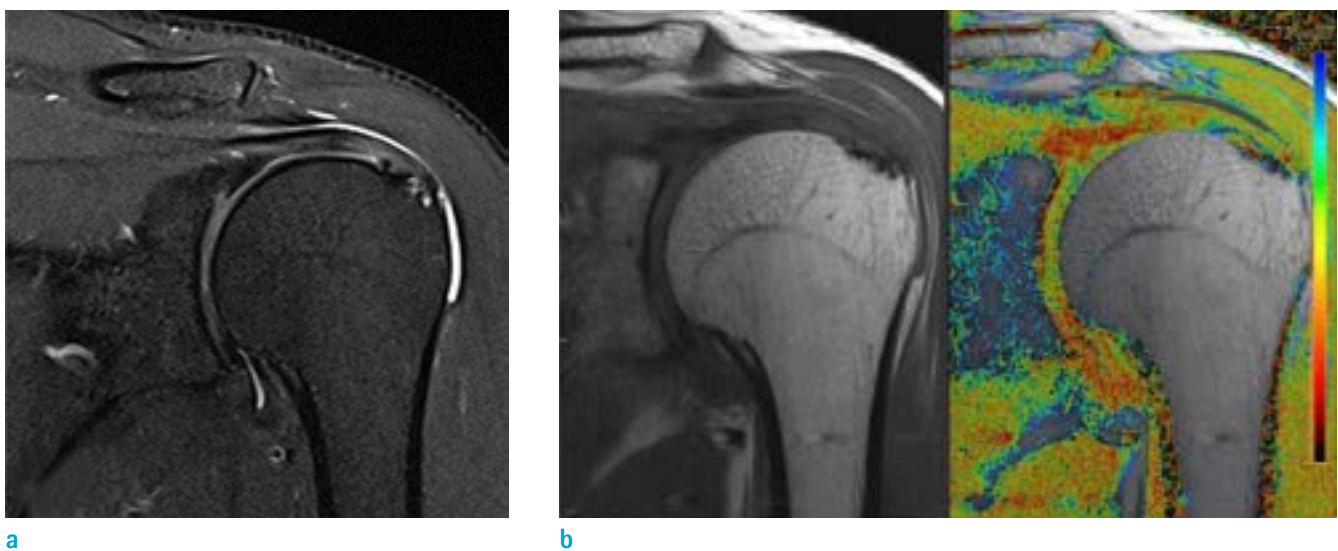
Fig. 2. (a) 46-year-old man with tendinopathy of rotator cuff and Goutallier grade 2. (b) The T2 map of the glenohumeral joint indicates slightly lower T2 value compared to the reported normal range. (The mean T2 value of reader 1; glenoid [41.88 ms], humeral head [41.95 ms], the mean T2 value of reader 2; glenoid [38.60 ms], humeral head [43.30 ms].)

no significant difference in the humeral head cartilage according to reader 1 and in the glenoid and humeral head cartilage according to reader 2. There was no statistical correlation between the acromiohumeral distance and the mean T2 values of the articular cartilage of all of the sub-regions of the glenoid and humeral head for both reader 1 or reader 2 (Table 4) (Fig. 3).

The mean T2 values of the sub-regions were similar to those of the mean T2 values of all sub-regions, and only exhibited slight differences. The mean T2 values of articular cartilage of the glenoid and humeral head for each sub-region based on the degree of rotator cuff tear are described as in Table 5. There were no significant differences between the mean T2 values among the groups and no tendency

to increase or decrease for both reader 1 and reader 2. However, for reader 2, the mean T2 values of the sub-region AI of the humeral head of the normal or tendinopathy group was higher for reader 2 than in the other groups.

The mean T2 values of articular cartilage of the glenoid and humeral head in each sub-region based on the degree of fatty atrophy of the supraspinatus muscle are described as in Table 6.

Reader 1: The mean T2 values of articular cartilage of the glenoid and humeral head cartilage exhibited a tendency to have higher mean T2 values for the fatty atrophy 3 or fatty atrophy 4 groups. However, sub-region PS was the only one that showed a statistically significant difference in the glenoid cartilage. In the humeral head cartilage, sub-regions

a

b

c
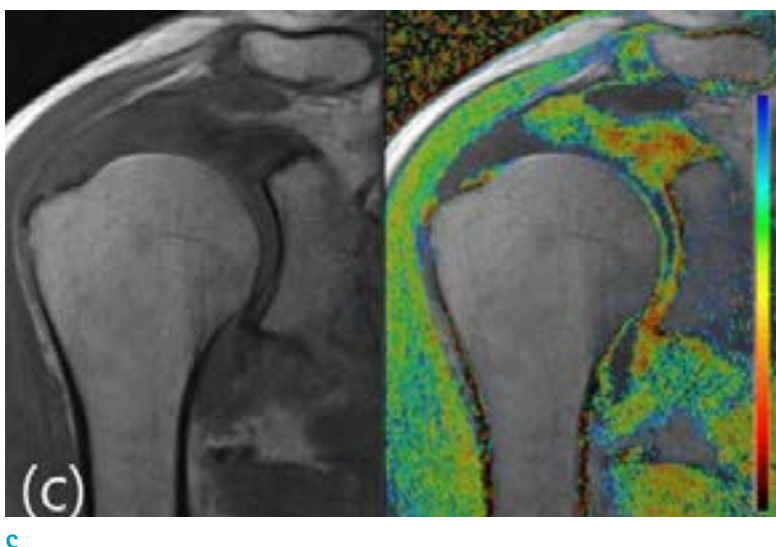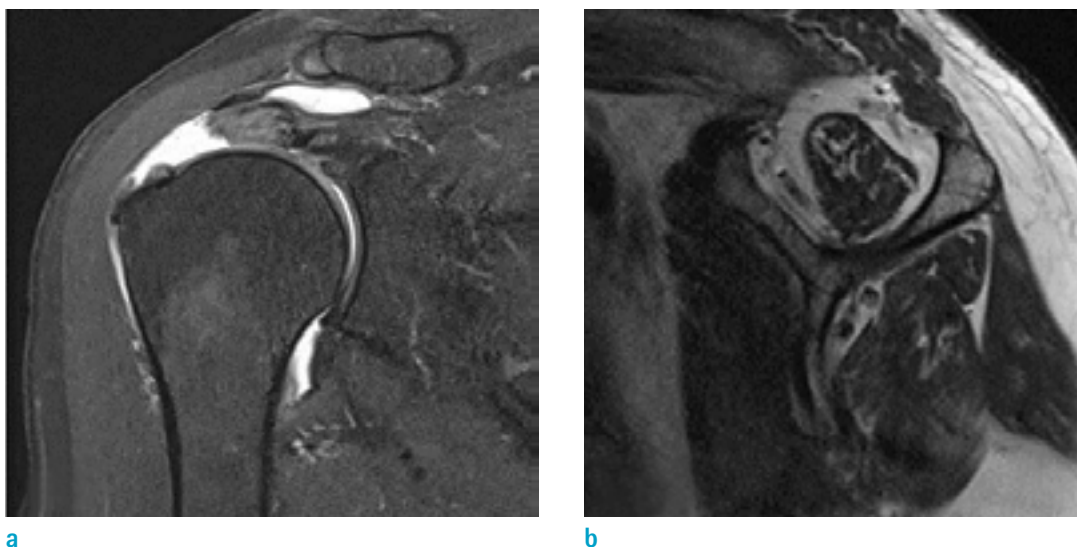
Fig. 3. (a, b) 76-year-old woman with full thickness tear of rotator cuff and Goutallier grade 3. (c) The T2 map of the glenohumeral joint showing higher T2 value compared to the reported normal range. The mean T2 value of glenoid according to reader 2 was similar with the reported normal range. (The mean T2 value of reader 1; glenoid [99.15 ms], humeral head [59.43 ms], the mean T2 value of reader 2; glenoid [47.57 ms], humeral head [56.40 ms])

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Table 4. The Acromiohumeral Distance and the Mean T2 Values (ms) of the Articular Cartilage of All Sub-regions of the Glenoid and Humeral Head
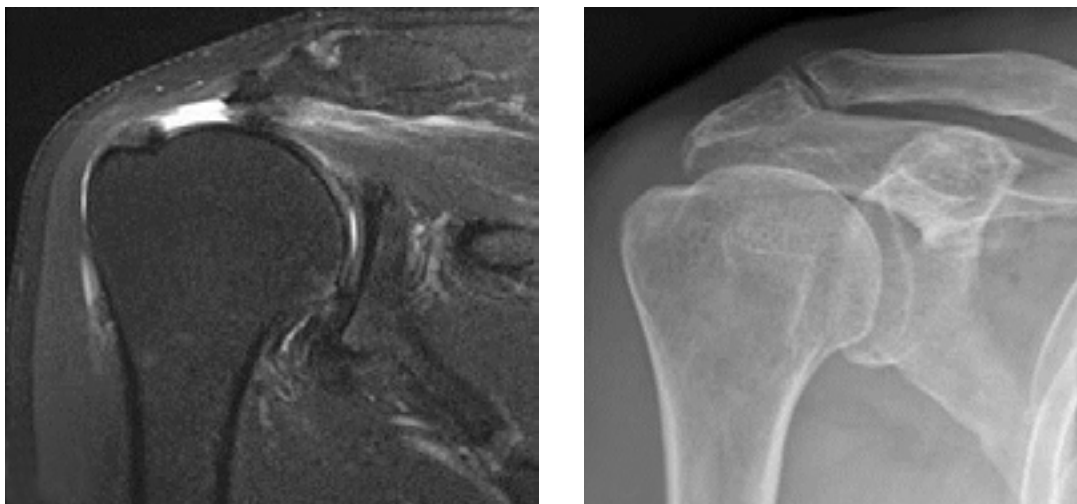
			Unstandardized coefficients		t	Significance	F	R^2
			B	Std. error				
All sub-regions'	Reader 1	Glenoid	−1.384	1.433	−0.966	0.338	0.933	0.015
		Humeral head	0.482	1.531	0.315	0.754	0.099	0.002
	Reader 2	Glenoid	−0.339	1.512	−0.224	0.823	0.050	0.001
		Humeral head	0.991	0.861	1.151	0.254	1.325	0.022

*B: unstandardized beta
**t: t-test statistic
***F: F value
****R^2: R-squared

a

b
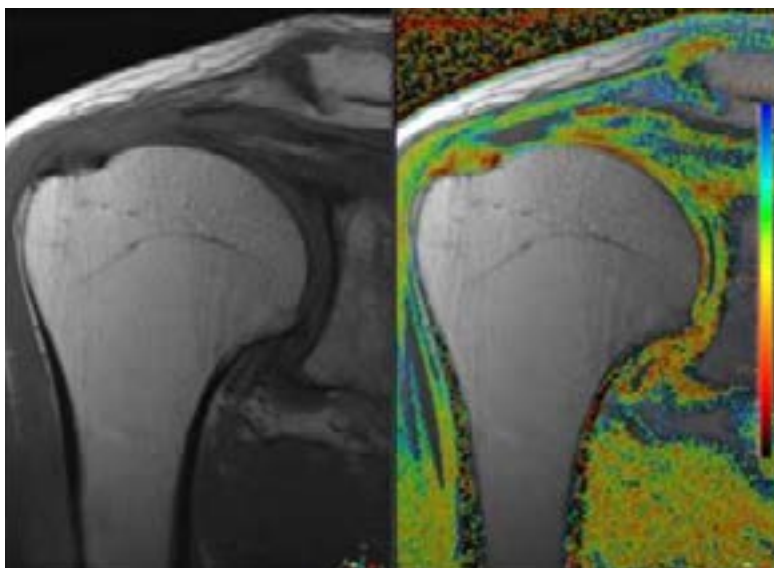
c

Fig. 4. (a, b) 72-year-old man with full thickness tear of rotator cuff and decreased acromiohumeral distance (AHD; 6.90 cm). (c) The T2 map of the glenohumeral joint indicates similar or slightly lower T2 value compared to the reported normal range. (The mean T2 value of reader 1; glenoid [45.35 ms], humeral head [48.91 ms], the mean T2 value of reader 2; glenoid [47.70 ms], humeral head [41.90 ms])

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of AI, MS and MI showed significant differences.

Reader 2: The mean T2 values of articular cartilage of the glenoid and humeral head cartilage had a tendency of higher mean T2 values in the fatty atrophy 3 or fatty atrophy 4 groups. However, the mean T2 values of the glenoid cartilage showed no statistically significant difference in any sub-region, and the mean T2 value of humeral head cartilage varied significantly in sub-regions of PS and PI.

The acromiohumeral distance and the mean T2 value of the articular cartilage for each sub-region of the humeral head and glenoid did not show statistical correlation for both reader 1 or reader 2 (Table 7).

DISCUSSION

Unlike the knee and hip joint, shoulder is not a weight-bearing joint. Nevertheless, osteoarthritis in shoulders is common particularly in those who have instability in shoulders (11). Chalmers et al. (12) reported that it takes about eight years to visualize minimal radiographic glenohumeral arthritic change in the early to middle stages of degenerative rotator cuff disease. Conventional imaging solutions, including plain radiographs, CT, and MR imaging had limitations in appropriately detecting and evaluating glenohumeral arthritic changes in patients with degenerative rotator cuff disease. Therefore, it is necessary to evaluate osteoarthritis of the glenohumeral joint using

Table 5. The Mean T2 Values (ms) of Articular Cartilage of Sub-regions of the Glenoid and Humeral Head According to the Degree of Rotator Cuff Tear for Reader 1 and Reader 2

			Grade 1 (n = 20)	Grade 2 (n = 21)	Grade 3 (n = 22)	F ratio	P value
Reader 1	Glenoid	AS	53.11 ± 18.75	50.11 ± 23.56	48.03 ± 17.63	0.336	0.716
		AI	38.04 ± 11.91	39.73 ± 13.82	41.17 ± 14.55	0.282	0.756
		MS	51.88 ± 18.68	43.42 ± 6.66	52.31 ± 23.59	1.651	0.200
		MI	41.90 ± 13.50	46.32 ± 34.87	41.91 ± 14.15	0.256	0.775
		PS	50.97 ± 17.17	45.13 ± 8.23	65.53 ± 61.86	1.634	0.204
		PI	39.00 ± 9.95	39.41 ± 10.35	41.35 ± 16.53	0.206	0.814
	Humeral head	AS	66.74 ± 31.01	53.61 ± 11.70	56.90 ± 14.17	2.263	0.113
		AI	48.23 ± 11.61	44.15 ± 11.59	53.76 ± 18.84	2.366	0.103
		MS	59.98 ± 16.33	51.98 ± 8.68	52.88 ± 10.76	2.616	0.081
		MI	49.72 ± 21.34	42.77 ± 10.01	61.27 ± 52.16	1.666	0.198
		PS	53.07 ± 16.29	49.76 ± 6.35	52.88 ± 16.36	0.379	0.686
		PI	60.21 ± 48.23	43.76 ± 12.11	53.95 ± 25.45	1.402	0.254
Reader 2	Glenoid	AS	46.03 ± 12.66	48.31 ± 22.92	48.95 ± 16.22	0.154	0.858
		AI	39.98 ± 10.85	37.62 ± 8.96	40.72 ± 15.71	0.371	0.692
		MS	66.51 ± 88.34	45.36 ± 17.98	48.39 ± 24.42	0.958	0.389
		MI	40.51 ± 11.82	41.34 ± 15.10	42.44 ± 20.96	0.072	0.931
		PS	41.48 ± 6.34	60.26 ± 80.46	46.93 ± 12.05	0.870	0.424
		PI	40.32 ± 13.22	39.32 ± 6.81	39.95 ± 10.17	0.049	0.952
	Humeral head	AS	57.31 ± 14.75	52.74 ± 14.97	53.01 ± 11.68	0.702	0.500
		AI	52.53 ± 17.89	42.04 ± 6.07	47.20 ± 9.69	3.844	0.027
		MS	50.85 ± 8.02	48.94 ± 8.84	49.86 ± 7.16	0.291	0.749
		MI	46.71 ± 17.29	42.26 ± 8.91	48.72 ± 16.63	1.070	0.349
		PS	46.85 ± 6.86	47.89 ± 6.78	45.79 ± 7.78	0.459	0.634
		PI	43.87 ± 16.55	38.69 ± 4.14	48.47 ± 22.88	1.864	0.164

AI = anteroinferior; AS = anterosuperior; MI = middle-inferior; MS = middle-superior; PI = posteroinferior; PS = posterosuperior

advanced techniques at a suitable stage in this study due to the high correlation between degenerative rotator cuff disease and degenerative changes of articular cartilage of the glenohumeral joint. Consequently, accurate diagnosis of both diseases is important in understanding the symptoms of patients with shoulder pain and predicting their prognosis (13-16).

Conventional MRI has been routinely utilized to estimate and evaluate rotator cuff disease and glenohumeral osteoarthritis, and had a key role in identifying morphologic changes of tendon and articular cartilage of the glenohumeral joint (17). However, conventional MRI has exhibited some limitations in the detection of minimal changes in the articular cartilage of degenerative disease

of the glenohumeral joint. Thus, quantitative techniques, such as T2 and T1rho mapping techniques and dGEMRIC technique, have been developed and recommended as monitoring tools of cartilage imaging during the treatment of osteoarthritis (15, 18–20).

There are numerous reports indicating T2 mapping as useful for investigating degenerative cartilage in patients with osteoarthritis of the knee joint (21, 22). However, there are just a handful of published studies about T2 mapping for articular cartilage of the glenohumeral joint. Maizlin et al. (15) submitted that T2 maps of articular cartilage of the glenohumeral joint correlate with the findings obtained on conventional MRI (23-25). In this study, the mean T2 values of articular cartilage of the humeral head and

Table 6. The Mean T2 Values (ms) of Articular Cartilage of Sub–regions of the Glenoid and Humeral Head According to the Degree of Fatty Atrophy of Supraspinatus for Reader 1 and Reader 2

			Goutallier grade 1 (n = 8)	Goutallier grade 2 (n = 48)	Goutallier grade 3 (n = 3)	Goutallier grade 4 (n = 4)	F ratio	P value
Reader 1	Glenoid	AS	48.26 ± 15.10	49.85 ± 21.21	62.53 ± 10.75	48.26 ± 15.10	0.404	0.751
		AI	36.50 ± 7.60	39.34 ± 13.67	42.33 ± 7.50	40.04 ± 15.41	0.760	0.521
		MS	56.71 ± 27.06	45.81 ± 11.48	66.70 ± 32.47	61.85 ± 37.75	2.845	0.045
		MI	42.33 ± 14.42	43.97 ± 25.43	42.93 ± 9.71	38.68 ± 5.72	0.070	0.976
		PS	57.24 ± 23.86	46.38 ± 10.32	145.87 ± 145.43	71.73 ± 61.47	9.246	0.000
		PI	40.04 ± 15.41	39.67 ± 12.55	48.53 ± 13.06	36.80 ± 7.41	0.544	0.654
	Humeral head	AS	66.11 ± 17.03	56.73 ± 21.76	83.37 ± 7.98	66.11 ± 17.03	2.084	0.112
		AI	46.43 ± 16.59	46.79 ± 10.41	56.13 ± 18.67	65.69 ± 66.22	4.540	0.006
		MS	64.53 ± 20.42	52.87 ± 9.77	68.70 ± 18.08	48.65 ± 4.24	4.039	0.011
		MI	49.31 ± 26.70	47.98 ± 19.50	43.90 ± 4.61	102.78 ± 111.56	3.696	0.017
		PS	50.71 ± 16.85	50.69 ± 10.03	59.50 ± 12.68	63.08 ± 35.67	1.366	0.262
		PI	65.69 ± 66.22	49.41 ± 21.63	76.33 ± 59.27	46.00 ± 6.70	1.223	0.309
Reader 2	Glenoid	AS	46.20 ± 14.44	46.82 ± 17.85	64.90 ± 11.50	46.20 ± 14.44	1.043	0.380
		AI	40.58 ± 14.98	38.64 ± 11.40	39.53 ± 7.53	35.54 ± 6.72	0.581	0.630
		MS	55.39 ± 30.62	52.36 ± 58.08	75.03 ± 51.25	41.45 ± 7.57	0.237	0.870
		MI	37.53 ± 8.02	42.19 ± 18.16	43.83 ± 10.98	38.73 ± 5.47	0.237	0.870
		PS	38.60 ± 6.48	51.98 ± 53.60	54.83 ± 6.90	39.83 ± 3.45	0.247	0.863
		PI	35.54 ± 6.72	40.43 ± 10.89	45.37 ± 8.17	37.48 ± 6.52	0.891	0.451
	Humeral head	AS	56.04 ± 9.65	53.61 ± 14.65	66.80 ± 11.70	56.04 ± 9.65	1.075	0.367
		AI	51.25 ± 20.03	46.15 ± 11.80	53.20 ± 5.98	38.93 ± 5.10	0.599	0.618
		MS	50.54 ± 6.54	49.47 ± 8.07	59.60 ± 7.45	46.00 ± 4.90	1.971	0.128
		MI	42.98 ± 10.84	45.72 ± 15.74	58.77 ± 14.75	44.68 ± 4.68	0.868	0.463
		PS	46.33 ± 6.11	46.86 ± 6.57	55.80 ± 10.10	40.70 ± 9.05	2.828	0.046
		PI	38.93 ± 5.10	42.94 ± 13.73	71.67 ± 53.74	42.23 ± 7.76	3.363	0.025

AI = anteroinferior; AS = anterosuperior; MI = middle-inferior; MS = middle-superior; PI = posteroinferior; PS = posterosuperior

glenoid of the glenohumeral joint were highly correlated to the reported mean T2 values of the study of asymptomatic patients and were similar or slightly correlated to the reported mean T2 values of the study involving healthy volunteers. However, in the fatty atrophy group 3, the mean T2 values were higher than the reported mean values of asymptomatic patients and healthy volunteers in both glenoid cartilage and humeral head cartilage. Therefore, this is a preliminary study that demonstrates that T2 mapping imaging is a promising technique that can quantitatively

evaluate biochemical changes associated with early OA in symptomatic patients with rotator cuff disease.

In this study, the mean T2 values of the groups categorized by the degree of rotator cuff tear did not show any statistically significant difference or tendency. Most of the dynamic restraint of the glenohumeral joint are due to the concavity-compression mechanism of the rotator cuff. As a result, when a rotator cuff tear occurs, these stabilizing forces are lost and this allows greater displacement of the humeral head. These pathologic contacts of the

Table 7. The Acromiohumeral Distance and the Mean T2 Values (ms) of the Articular Cartilage of Sub-regions of the Glenoid and Humeral Head

			Unstandardized coefficients		t	Significance	F	R^2
			B	Std. error				
AS	Reader 1	Glenoid	0.391	2.030	0.193	0.848	0.037	0.001
		Humeral head	0.558	2.169	0.257	0.798	0.066	0.001
	Reader 2	Glenoid	−0.171	1.821	−0.094	0.925	0.009	0.000
		Humeral head	0.863	1.420	0.608	0.546	0.369	0.006
AI	Reader 1	Glenoid	−0.910	1.380	−0.660	0.512	0.435	0.007
		Humeral head	0.721	1.540	0.468	0.641	0.219	0.004
	Reader 2	Glenoid	−0.139	1.257	−0.111	0.912	0.012	0.000
		Humeral head	1.820	1.106	1.646	0.105	2.711	0.043
MS	Reader 1	Glenoid	−1.659	1.864	−0.890	0.377	0.792	0.013
		Humeral head	1.173	1.295	0.906	0.368	0.821	0.014
	Reader 2	Glenoid	−3.897	5.449	−0.715	0.477	0.511	0.008
		Humeral head	0.130	0.816	0.159	0.874	0.025	0.000
MI	Reader 1	Glenoid	0.252	2.366	0.106	0.916	0.011	0.000
		Humeral head	−1.681	3.514	−0.478	0.634	0.229	0.004
	Reader 2	Glenoid	0.059	1.691	0.035	0.972	0.001	0.000
		Humeral head	0.510	1.531	0.333	0.740	0.111	0.002
PS	Reader 1	Glenoid	−6.480	3.910	−1.657	0.103	2.746	0.044
		Humeral head	−0.654	1.410	−0.464	0.644	0.215	0.004
	Reader 2	Glenoid	1.788	4.875	0.367	0.715	0.135	0.002
		Humeral head	0.879	0.716	1.229	0.224	1.510	0.025
PI	Reader 1	Glenoid	0.102	1.306	0.078	0.938	0.006	0.000
		Humeral head	2.776	3.297	0.842	0.403	0.709	0.012
	Reader 2	Glenoid	0.326	0.942	0.346	0.730	0.120	0.002
		Humeral head	1.742	1.661	1.049	0.298	1.101	0.018

*B : unstandardized beta
**t : t-test statistic
***F : F value
****R^2: R-squared
AI = anteroinferior; AS = anterosuperior; MI = middle-inferior; MS = middle-superior; PI = posteroinferior; PS = posterosuperior

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humerus, the glenoid and coracoacromial arches generates frictional wear of the articular cartilage besides the subacromial impingement (26-28). This pathophysiologic mechanism helps us to understand that glenohumeral joints with tendinopathy, partial thickness tears, and small symptomatic full thickness tears of the rotator cuff have a slower rate of progress of degenerative articular cartilage disease. Significant degenerative cartilage changes are expected to occur after a certain period of time even after the occurrence of a massive tear (29, 30).

In this study, the Goutallier grade 3 group exhibited higher mean T2 values when there was a correlation between the fatty degeneration of the supraspinatus muscle and the mean T2 values of glenohumeral articular cartilage, in addition to some sub-regions where there was a significant difference. The fatty degeneration of the rotator cuff muscles is an key factor influencing the function of the shoulder, the reparability of the cuff tears and the outcome of the cuff tears (3, 31, 32). Mechanical detachment of the tendon in rotator cuff tears and suprascapular nerve injury is a major factor of fatty degeneration in rotator cuff muscles (33). Considering that the changes in the fatty infiltration and atrophy of the rotator cuff are irreversible, loss of the stabilizing force in the rotator cuff muscle tear patients with severe fatty atrophy is lengthy and may lead to the degeneration of articular cartilage or the possibility of early osteoarthritis. The study results are supported by reports indicating that glenohumeral arthritis is associated with rotator cuff atrophy and fatty infiltration. Naimark et al. submits that glenohumeral arthritis is related to rotator cuff atrophy and fatty infiltration (34, 35).

Reduction of the acromiohumeral distance (AHD) through conventional anteroposterior radiographs of the shoulder is known to assist in predicting tear and irreparability of rotator cuff tendons (36, 37). However, the acromiohumeral distance and the degenerative change of glenohumeral articular cartilage, identified via the mean T2 values of cartilage, did not show a significant correlation in this study. This may be due to association of osteoarthritis with some degree of decentralization of the glenohumeral joint except superior stability. Nadja Saupe et al. (38) reported that more than 90% of patients with an acromiohumeral distance ≤ 7 mm had a full-thickness tear of the supraspinatus tendon, while 67% had a full-thickness tear of the infraspinatus tendon, and the size of a rotator cuff tear and the degree of fatty degeneration of the infraspinatus muscle had the most pronounced effect on the acromiohumeral distance. Consequently, a massive tear coupled with impairment of

at least two tendons, the supraspinatus and infraspinatus tendons may show a decrease in AHD, while a full thickness tear of one tendon and a partial thickness tear of the rotator cuff tendon do not indicate a significant decrease in AHD (39). In fact, only one case recorded an AHD of less than 7 mm in this study.

In this study, measurement of T2 value was done using MR images obtained using two different scanners. However, the sequence and parameters of most of the imaging for T2 mapping was the same. Thus far, literature on reproducibility concerning T2 value of cartilage are rare. Lammentausta et al. (40) reported variations in T2 values of knee cartilage obtained by scanners from different manufacturers. However, they suggested that the variation in T2 was likely due to difference in pulse sequences rather than manufacturing factors. In this study, inter-observer reproducibility of both measurements of mean T2 values of articular cartilage of glenohumeral joint from reader 1 and reader 2 indicate moderate reproducibility in the glenoid and good reproducibility in the humeral head. Koff et al. (41) reported that different repeatability of patellar cartilage T2 values occur among examiners due to different ROIs as defined by examiners. Recent literature offer different opinions. Mosher et al. (42) reported that MR imaging measurements of T2 value presented moderate to excellent reproducibility in the analysis of MR image biomarker (T2 and patellar $T1-\rho$) reproducibility of knee cartilage in a multi-center multi-vendor trial. Glaser et al. (43) also suggested that there was no noticeable difference between intra- and inter-session reproducibility in the study about regional precision errors of T2 in healthy human patellar cartilage. In addition, we should be aware of bias in cartilage T2 value and interpreting T2 mapping which results from the magnetic field strength, MR acquisition protocol, calculation techniques, technical precision and re-segmentation precision, and process of optimization of practice in MR examinations is key (44).

Here are some of the limitations of this study:

First, as this is a retrospective study design, there may be existence of selection bias. The number of patients with atrophy fatty atrophy 3 or fatty atrophy 4 was relatively small. Consequently, further studies involving more patients with fatty atrophy 3 or fatty atrophy 4 are required. Secondly, it was difficult to measure the precise T2 value of articular cartilage while excluding surrounding tissues such as joint effusion or subchondral bone, and this may be as a result of poor contrast between cartilage and the

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surrounding tissue, and the partial volume effect or the chemical shift artifact. In order to reduce the error of T2 mapping analysis and to be practical and reproducible in the normal clinical workflow in future, automated segmentation and registration routines should be effected. We believe that a further developed technique which may reduce this limitations and enable high resolution imaging will be possible in the subsequent study. Third, not all findings were confirmed by arthroscopic surgery or histology.

In conclusion, T2 mapping of the glenohumeral joint did not show a significant difference in the quantitative assessment of the degenerative change of the articular cartilage based on the degree of rotator cuff tear. However, it provides additional quantitative information regarding the degenerative change of cartilage of the glenohumeral joint in patients with rotator cuff tear and severe fatty atrophy of the rotator cuff.

Acknowledgments

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