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Evaluation of Humeral Head Cartilage Using the Magnetic Resonance Imaging T1 ρ Relaxation Time Mapping Technique: A Comparison between Young and Elderly Healthy People

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Abstract

Objective: To evaluate the difference in the age-related cartilage changes of the humeral head with T1ρ relaxation time mapping and assess the normal distribution of the proteoglycan content of the humeral head in healthy volunteers without any symptoms or structural disorders.

Materials and Methods: Twenty male volunteers (10 young subjects, 10 elderly subjects) for each generation group (mean age, young subjects: 30.2 ± 2.3 years; elderly subjects: 62.6 ± 6.2 years) participated in this study. Spectral attenuated inversion recovery T2-weighted imaging and T1ρ relaxation time mapping were performed using 3.0-Tesla magnetic resonance imaging. Regions of interest were located on the humeral cartilage on oblique coronal images from the bone–tendon junction to the inferior articular surface and divided the surface of the humeral cartilage into 6 areas. The T1ρ values of each area of the humeral head were measured and compared between groups.

Results: The total mean T1ρ values were 40.9 ± 5.3 and 40.5 ± 3.5 ms for young and elderly volunteers, respectively. Comparison between ages showed no significant differences in the T1ρ values between each corresponding area. The T1ρ values of the inferior area of the humeral head in both young and elderly volunteers were significantly higher than those of the superior area.

Conclusion: No marked age-related differences in the T1ρ values of the humeral head were observed between young and elderly volunteers without any symptoms or structural disorders. However, the T1ρ values in the inferior area of the humeral head were increased compared with those in the superior area.

Keywords: Age; Cartilage; Humeral head; Magnetic resonance imaging; Proteoglycan; Shoulder; T1ρ (T1 rho) relaxation time mapping

Introduction

Age-related degenerative cartilage change in a shoulder joint is a common disease. Several studies about the association of age and degenerative cartilage change in a humeral head are available. Hawellek et al. [1] found that age significantly influences the histological osteoarthritis grade but does not directly influence cartilage calcification. A decrease in proteoglycan (PG) content is an aspect of cartilage degeneration. Huber-Bruning et al. [2] investigated the PG content of the cartilage of the humeral head in a cadaveric study; they found that PG content decreases in cadavers aged over 40 years. However, both studies did not exclude patients with age-related structural disorders which accordingly lead to the cartilage degeneration of the humeral head [3].

T1ρ (rho) mapping by magnetic resonance imaging (MRI) has recently emerged as a new method for evaluating cartilage. T1ρ mapping is indicative of PG depletion [4]. Previous studies showed that T1ρ values increase as PG decreases, and this method retains sensitivity even in the very early change of PG. T1ρ relaxation time mapping is used to evaluate the knees and hip joints [5]. Only one study reported T1ρ relaxation time mapping of the glenohumeral joint. Nardo et al. [6] used a combined T1ρ–T2 mapping sequence and evaluated the cartilage of the shoulder joint. T1ρ relaxation time mapping may be useful for evaluating age-related cartilage changes. However, no studies have examined these changes in the shoulder joints of healthy volunteers, particularly those who were excluded due to any symptoms or structural disorders.

We hypothesized that the T1ρ values of the healthy humeral head cartilage in elderly people may be higher than those in younger people according to the increase in age. This study is aimed to determine whether there are or are not age-related changes that can be detected by MRI T1ρ relaxation time mapping in completely normal humeral head, and to investigate the distribution of the T1ρ values.

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Materials and Methods

Subject characteristics

Twenty-two male volunteers without any symptoms of the shoulders participated in this study. Only male volunteers were included to avoid sex differences. They all lacked any remarkable history of shoulder pain and also did not have history of trauma, rheumatoid arthritis, connective tissue disease, or any other kind of joint disease. For MRI, volunteers with structural disorders were excluded from the study (n=2, males, ages 70 and 72). In total, the subjects consisted of 10 young male volunteers (mean age of 30.2 ± 2.3 years) and 10 elderly male volunteers (mean age of 62.6 ± 6.2 years). A cohort study of the residents of a mountain village with the ultrasonographic examinations [7] showed that the dominant side of the shoulder is at an increased risk of asymptomatic rotator cuff tears; therefore, all of the participants underwent MRI for the non-dominant shoulder (young subjects: 10 left, elderly subjects: 4 right and 6 left). This study was approved by the University Institutional Ethics Board and in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study.

MRI protocols

The current study was performed using MRI with a 3.0-Tesla system (Achieva 3.0T, Quasar Dual; Philips Healthcare, Best, The Netherlands) and a sensitivity-encoding shoulder 4-channel coil.

Spectral attenuated inversion recovery (SPAIR) T2-weighted imaging and T1ρ relaxation time mapping were performed. SPAIR was carried out using the following parameters: repetition time (TR), 3.025 ms; echo time (TE), 60 ms; flip angle, 90°; turbo spin echo factor, 12; field of view (FOV), 140 × 140 mm; matrix, 284 × 250; slice thickness, 3 mm; slice gap, 0 mm; bandwidth, 217.4 Hz/pix; number of slices, 10; number of excitations (NEX), 2; and total scan time, 3 min 56 s. T1ρ relaxation time mapping was conducted using the following parameters: TR, 4.6 ms; TE, 2.3 ms; flip angle, 35°; FOV, 140 × 140 mm; matrix, 256 × 175; slice thickness, 3 mm; slice gap, 0 mm; bandwidth, 719.5 Hz/pix; number of slices, 10; NEX, 2; spin-lock pulse frequency, 500 Hz; time of spin-lock (TSL), 1, 20, 40, and 60 ms; and total scan time, 4 min 58 s. We used a low flip angle, but it did not affect the T1ρ contrast because a shot interval of 6,000 ms was used between each slice acquisition and k-space was filled low-high ordering. The maps were produced with the Philips Research Integrated Development Environment software program written in Interactive Data Language (IDL 6.3; ITT Inc., Boulder, CO, USA).

Assessment of T1ρ relaxation time mapping

The Medical Image Processing, Analysis, and Visualization (MIPAV) software program (Biomedical Imaging Research Services Section, Center for Information Technology, National Institutes of Health, Bethesda, MD, USA) was used for the data analysis. The center slice of the coronal plane of the T1ρ image was determined as the maximum diameter of the humeral head, and a circle was drawn on the humeral head. From the tendon–bone interface to the glenohumeral joint cartilage, fan-shaped regions of interest (ROIs) were drawn and divided into 6 areas (I–VI) with reference to the SPAIR T2-weighted images (Figure 1). The subchondral areas were determined to be the deep blue zones using the MIPAV software. One layer above the deep blue areas was plotted to represent the cartilage of the humeral head (Figure 2). Special care was taken to avoid the joint fluid or the subchondral bone to be plotted. For each ROI, the mean T1ρ value was calculated. Pre- and post-slices of the center slice were plotted and equilibrated for three ROIs to improve the accuracy.

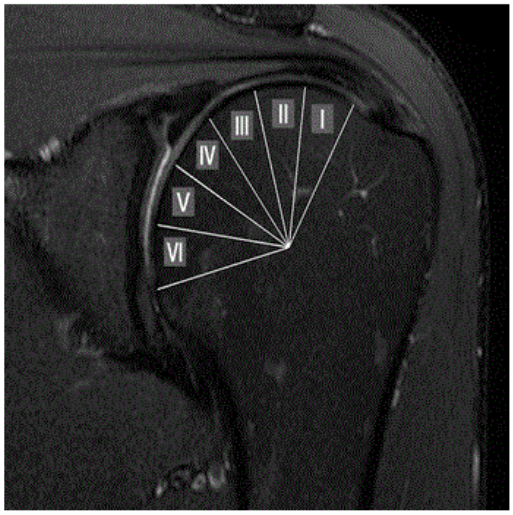

Figure 1: Six areas of the humeral head divided equally.

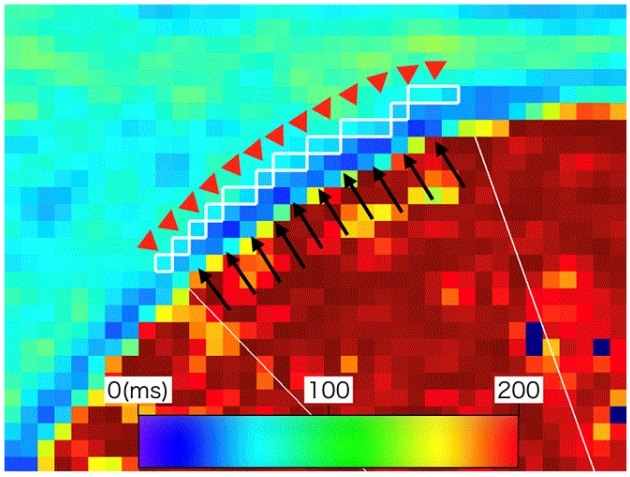

Figure 2: Enlarged area of the humeral head. The deep blue areas pointed out by black arrows represent the subchondral bones. The layer above the deep blue areas, denoted by red triangles, represents the cartilage areas.

Reproducibility of measurements

To quantify the intraobserver reproducibility, all measurements in each ROI were calculated three times following an interval of at least 4 weeks, and the T1ρ values of each ROI were then equilibrated. All measurements were independently calculated by two observers (G.M. and N.T., with 10 and 16 years of orthopedic surgery experience, respectively) to quantify the interobserver reproducibility.

Statistics

The Wilcoxon rank sum test was performed for the differences between the T1ρ values of each ROI in the same volunteer. The Steel–Dwass test was used to compare the T1ρ values in young and elderly volunteers. $p<0.05$ was considered statistically significant. All of the statistical analyses were performed with the JMP software program (version 11.0; SAS Institute, Cary, NC, USA). The intra- and interobserver reliabilities were evaluated using the intraclass correlation coefficient (ICC) obtained with the R software program (version 3.2.4; R development core team, Vienna, Austria).

Results

A total of 360 ROIs (18 ROIs per volunteer) were evaluated. The total mean T1ρ values were 40.9 ± 5.3 and 40.5 ± 3.5 ms for young and elderly volunteers, respectively. Statistical differences were not observed in the values between the young and elderly volunteers (p=0.8102). No statistical differences were found in the T1ρ values of young and elderly volunteers between each corresponding area; the T1ρ values and p values are presented in Table 1.

	T1ρ values (ms): area					
	I	II	III	IV	V	VI
young volunteers	38.0 ± 3.6	36.5 ± 3.1	38.9 ± 4.0	42.5 ± 5.2	44.7 ± 5.1	45.0 ± 4.1
elderly volunteers	38.5 ± 2.8	37.9 ± 3.2	38.4 ± 2.0	41.5 ± 2.7	42.6 ± 3.0	44.1 ± 2.7
p value*	0.6232	0.3447	0.9698	0.7913	0.6232	0.5708

Table 1: T1ρ values of young and elderly volunteers of each area. *; Comparison of young and elderly volunteers using Steel-Dwass test.

The T1ρ values of the young volunteers are shown in Figure 3. The T1ρ values in area IV were significantly higher than those in area II (p=0.0140). The T1ρ values in area V were significantly higher than those in areas I (p=0.0046), II (p=0.0015), and III (p=0.0257). The T1ρ values in area VI were also significantly higher than those in areas I (p=0.0036), II (p=0.0004), and III (p=0.0091). In total, the T1ρ values in the inferior areas were significantly higher than those in the superior areas.

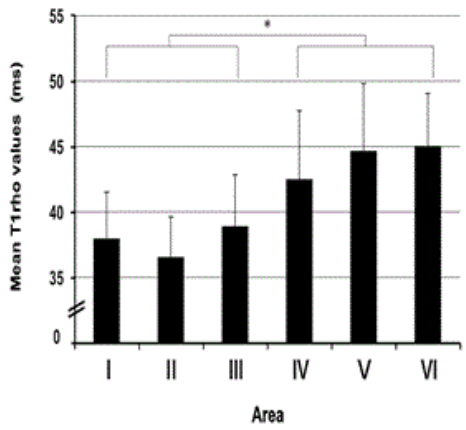

Figure 3: T1ρ values of the young volunteers.

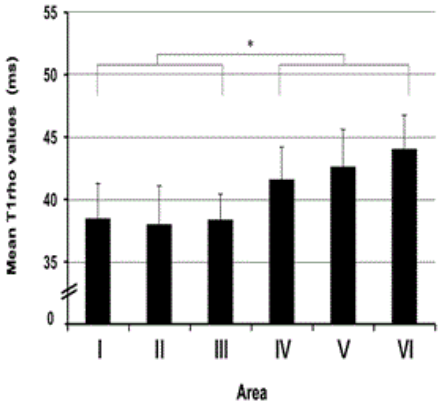

Figure 4: T1ρ values of the elderly volunteers.

The T1ρ values of the elderly volunteers are shown in Figure 4. The T1ρ values in area IV were significantly higher than those in areas I (p=0.0376), II (p=0.0211), and III (p=0.0211). The T1ρ values in area V were also significantly higher than those in areas I (p=0.0113), II (p=0.0073), and III (p=0.0036). The T1ρ values in area VI were significantly higher than those in areas I (p=0.0013), II (p=0.0010), and III (p=0.0002). The results are similar to those in young volunteers; the T1ρ values in the inferior areas were significantly higher than those in the superior areas.

As for the ICC, the intraobserver reliability of the measurements was 0.94, and the interobserver reliability, 0.83.

Discussion and Conclusion

We demonstrated that no statistical differences were observed between the T1ρ values in young and elderly volunteers, contrary to our hypothesis. However, several studies have observed the age-related cartilage changes of the humeral head as previously mentioned. Our results may be attributed to the selection of the 'healthy' subjects; we

excluded patients with any symptoms or structural disorders, which accordingly lead to PG depletion of the shoulders. The age-related loss of PG content in the humeral head is generally known, but age-related structural changes seem to be responsible for the age-related decrease of PG content.

A possible explanation for the present finding is the fact that the shoulder is a non-weight bearing joint. Hirose et al. [8] reported the T1ρ and T2 mapping of the proximal tibiofibular and femorotibial joints in relation to aging. In their report, the T1ρ and T2 values of the proximal tibiofibular joint cartilage were constant and not affected by age, whereas those of the femorotibial joint showed a positive correlation between cartilage degeneration and age. As shoulder is a non-weight-bearing joint, our findings might have exhibited a negative correlation with age.

We found that the T1ρ values were high in the inferior area of the humeral head in both young and elderly volunteers. In the stereophotogrammetry cadaveric study of Soslowsky et al. [9], they found that the humeral head contact migrates from an inferior region to a superior region, according to the humeral elevation. The glenohumeral contact areas were mostly in the inferior part of the humeral head when the elevation angle was 0° and in the middle to inferior parts when the angle was 60°. Soslowsky et al. also reported that the contact areas increase with increasing elevation until 120° and then decrease with further increased elevation at 180° of total arm elevation. Aizawa et al. [10] reported in a three-dimensional motion study that the shoulder needs to be elevated up to 140° to perform activities of daily living (ADL) with an electromagnetic three-dimensional tracking system. Sheikhzadeh et al. [11] also revealed that the maximum elevation angle of the movement in ADL is used to touch the contralateral shoulder, and the angle is 111° with the MotionMonitor system. According to these reports, shoulder movement in ADL seems to be responsible for the increase of the T1ρ values in the inferior area of the humeral head than in the superior area.

Kang et al. [12] conducted a feasibility study with T2 mapping of the articular cartilage of the glenohumeral joint. They concluded that the T2 values of the humeral cartilage showed spatial variation, with longer T2 values observed at the articular surface and a decreasing trend toward the bone-cartilage interface. These findings are comparable to the present study; they strongly support our results of decreasing PG content in the inferior area.

Several limitations of the present study warrant mention. First, the cartilage of the humeral head is thin compared with that of the knees and hip joints. The curvature of the humeral head results in a partial volume artifact that limits the ability to evaluate the cartilage. T1ρ relaxation time mapping of the humeral head is technically challenging [9], but we carefully counted the areas of the cartilage that lay only one layer above the subchondral bone. We believe that this technique is a quantitative, noninvasive method of evaluating the cartilage of the humeral head. Second, the findings were not confirmed by arthroscopy or histology. A histologic examination may result in different data.

In conclusion, this study showed no age-related T1ρ value changes of the humeral head for either young or elderly healthy volunteers without any symptoms or structural disorders. The T1ρ values in the inferior area of the humeral head were higher than those in the superior area for both groups.

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