T1ρ Magnetic Resonance Imaging for Detection of Patella Cartilage in Healthy Young Adults

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***Abstract*—Objective Prevalence study using T1ρ magnetic resonance imaging (MRI) of patella cartilage in healthy young adults, to determine if T1ρ MRI could assess early articular cartilage degeneration in knees.**

Methods PDWI and T1ρ images of the knee were obtained for 50 asymptomatic young subjects (23 men and 27 women; mean age, 23.86 yr), with a 3.0-T MRI scanner. T1ρ maps were generated from the 100 cases of patellar cartilage, and each map was divided into 15 regions of interest (ROIs). T1ρ values of each ROI was measured and compared with each other.

Results Differences in T1ρ value among different portions within the patellar cartilage, and T1ρ values showed a significant increase at the upper and lateral portions ($P < 0.05$). T1ρ values were no difference between corresponding ROIs in left and right knees ($P > 0.05$), except the central-lateral, central-medial and lower-medial portions.

Conclusion T1ρ values maybe sensitively detect the minimal changes of proteoglycan before the morphologic alterations within patellar cartilage. Therefore that T1ρ imaging can be potentially used as a clinical scale for quantitatively characterizing early cartilage degeneration in knees.

***Index terms*—Magnetic resonance; T1ρ imaging; T1ρ value; articular cartilage; Proteoglycan**

I. BANKGROUND

Degeneration of knee articular cartilage is a serious problem that causes pain and limits mobility, and the development of new magnetic resonance imaging (MRI) techniques for detection of early articular cartilage degeneration in knees is expected. T1ρimaging, different from conventional MRI that could only detect advanced degeneration of cartilage with morphological change, it is qualified to detect microscopic change [1, 2] in degeneration of cartilage tissue at molecular level. Therefore, we perform T1ρ MRI to detect degeneration of patella cartilage in healthy young adults, aiming for evaluation if which could depict the microstructural changes of early knee articular cartilage degeneration.

II. METHODS

Clinical data

Young healthy volunteers were randomly selected from college students. Inclusion criteria were Inclusion criteria were younger than 35 years, within the normal range (18.5-23.9) of body mass index (BMI), no history of mass movement, no history of knee joint trauma and operation, no family history of rheumatic arthritis, no clinical manifestation of knee osteoarthritis and no introversion and extroversion of knee joint in specialized physical examination, and those separation distance of two ankles was 4-6cm, tenderness of knee joint was negative, floating patella phenomenon was negative, ingression of patella was lower than half of the width. Exclusion criteria included being an athlete or smoker and having morphologic change of patellar cartilage in proton density weighted image (PDWI). The final roster included forty subjects (23 males and 27 females; mean age of 23.86 ± 1.8 years) with no difference in cohort age, BMI, height, or weight. The assessment of physical examination were completed by two orthopedists. The acquired PDWI images were examined by two radiologists with more than ten years of experience to reach an agreed diagnosis: abnormal images were excluded from the study. All participants provided written consents and this study was approved by the human research ethics committee of Jinan University, Guangzhou, China.

Magnetic Resonance Imaging Scanning Procedures

The subjects were scanned with the application of

knee joint coil, using a clinical 3.0T MRI scanner (GE Signa HD; the first affiliated hospital of Jinan University, Guangzhou, China). PDWI of the knees were performed previously on the axial view, for use as a screening tool for abnormal images, with the scanning parameters as follows: repetition time/time echo (TR/TE) = 1900 ms/30.2 ms, slice thickness/spacing (thn/spa) = 3 mm/0 mm, acquisition matrix = 320× 256, field of view (FOV) = 16 × 16 cm, number of excitation (NEX) = 1. The second MRI pulse sequence used for a series of T1ρ-weighted sagittal images was 3D Magnetization-Prepared Angle-Modulated Partitioned k-Space Spoiled Gradient Echo Snapshots (3D MAPSS) with a spin-lock pulse amplitude of 500 Hz, under the following parameters: TR = 6.8 ms, TE = 0, 10, 40, or 80 ms, thn/spa = 3 mm/0 mm, FOV = 16 × 16 cm, matrix = 288 ×192, NEX = 1, scan time = 3 min 33 s, and the B1 of spinlock radio frequency (RF) was 0.145 Gauss. All the scans were performed in the afternoon, and were selected six layers, according to fixed axis position of central layer perpendicular to patellar femoral articular surface in sagittal view.

Data Processing

The raw data of T1ρ MRI were transferred to the sun advantage workstation 4.5 and processed using GE Functool software, to generate the maps. Selecting three continuous layers (the 2nd, 3rd, 4th layer or 3rd, 4th, 5th layer) with largest patella cartilage, successively represents the upper, central and lower layer of cartilage, and each layer is roughly divided into lateral, partial lateral, middle, partial medial, medial regions. Thus, each map of patella cartilage is divided into fifteen regions of interest (ROIs), and T1ρ value was measured respectively. In order to reduce the influence of partial volume effect on results, the ROIs were not allowed to be set on the adjacent tissue.

Statistical analysis

The measured results were processed using the SPSS statistics software package (ver. 13.0; SPSS Inc. Chicago, Illinois, USA). A normal distribution was obtained using the normality test, and then paired sample T test and single-factor analysis of variance (one-way ANOVA) were applied to compare the differences in T1ρ values among different ROIs in the patellar cartilage. The obtained data were presented as mean ± standard deviation (SD). A P value of < 0.05 was considered statistically significant.

III. RESULTS

A total of 100 knee joints of 50 subjects were detected in this study by T1ρ MRI, and the clear images are obtained (Fig 1.). T1ρ values at fifteen ROIs of bilateral patellar cartilage in 50 asymptomatic young subjects are shown in Table 1. The mean T1ρ values at the upper, central and lower layer portions in patella cartilage were calculated according to the following formula: ($T1\rho_{mean}$) =(T1ρ lateral part of the same layer + T1ρ partial lateral part + T1ρ middle part + T1ρ partial medial part + T1ρ medial part)/5. The mean T1ρvalues of lateral, partial lateral, medial partial medial and medial portions in patella cartilage were solved by the following equation: ($T1\rho_{mean}$) =(T1ρ at corresponding part of upper layer + T1ρ at corresponding part of central layer + T1ρ at corresponding part of lower layer)/3 (See Table 2).

Table 1. T1ρ values at 15 ROIs of bilateral patellar cartilage in healthy young adults expressed as the mean ± standard deviation.

ROI	Left knee		Right knee	
	T1ρ (ms)	95% CI	T1ρ (ms)	95% CI
upper-lateral	37.87 ± 4.08	36.71 - 39.03	37.79 ± 3.9	36.69 - 38.91
central-lateral	36.26 ± 4.25	35.05 - 37.46	34.74 ± 4.15	33.56 - 35.92
lower-lateral	36.61 ± 4.25	35.41 - 37.82	36.64 ± 4.89	35.25 - 38.03
upper-partial lateral	35.75 ± 4.26	34.54 - 36.96	35.46 ± 3.19	34.56 - 36.37
central-partial lateral	34.05 ± 3.49	33.07 - 35.05	34.03 ± 4.01	32.88 - 35.17
lower-partial lateral	36.32 ± 4.58	35.02 - 37.62	35.64 ± 4.46	34.37 - 36.91
upper-middle	35.09 ± 3.89	33.98 - 36.19	35.54 ± 4.65	34.22 - 36.87
central-middle	33.93 ± 3.61	32.91 - 34.96	33.94 ± 4.44	32.68 - 35.21
lower-middle	35.47 ± 3.5	34.48 - 36.47	35.47 ± 4.3	34.24 - 36.69
upper-partial medial	35.58 ± 3.7	34.53 - 36.64	36.11 ± 4.58	34.81 - 37.41
central-partial medial	33.31 ± 3.87	32.21 - 34.41	33.35 ± 3.45	32.37 - 34.33
lower-partial medial	35.19 ± 3.7	34.14 - 36.25	35.02 ± 3.88	33.92 - 36.13
upper-medial	36.39 ± 4.21	35.19 - 37.59	36.66 ± 4.85	35.29 - 38.04
central-medial	34.69 ± 4.13	33.52 - 35.87	33.13 ± 3.35	32.18 - 34.09
lower-medial	35.76 ± 3.83	34.67 - 36.85	34.43 ± 3.93	33.31 - 35.54

There was no significant difference in T1ρ values of patellar cartilage between the left knees and right knees ($P = 0.1851$).

Table 2. Mean T1ρ values at different portions of bilateral patellar cartilage expressed as the mean ± standard deviation.

Portions	Left knee	Right knee

	$T1\rho_{mean}$ (ms)	95% CI	$T1\rho_{mean}$ (ms)	95% CI
upper-layer	36.13 ± 4.11	33.46 - 39.13	36.31 ± 4.33	33.2 - 39.58
central-layer	34.45 ± 3.97	31.77 - 36.93	33.84 ± 3.91	30.96 - 36.82
lower-layer	35.43 ± 4.48	32.86 - 38.62	35.2 ± 4.44	32.05 - 37.87
lateral	36.91 ± 4.22	34.25 - 39.83	36.39 ± 4.49	33.09 - 39.47
partial lateral	35.38 ± 4.22	32.47 - 38.52	35.05 ± 3.96	32.37 - 35.24
middle	34.83 ± 3.71	32.36 - 37.51	34.98 ± 4.5	31.88 - 38.65
partial medial	34.69 ± 3.86	32.58 - 37.24	34.83 ± 4.13	31.5 - 37.54
medial	35.62 ± 4.09	32.22 - 38.55	34.75 ± 4.32	31.09 - 37.84

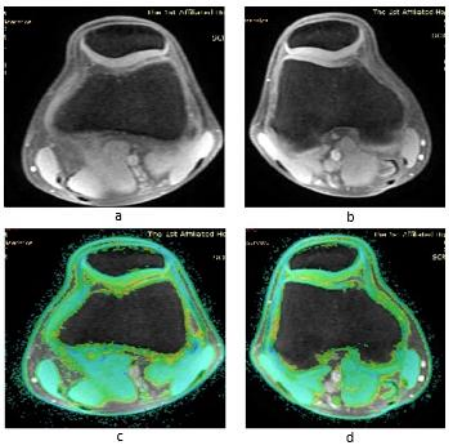

Figure 1. T1ρ images of the bilateral knees obtained from the healthy young adults. T1ρ original images of left (a) and right (b) knees show normal signal on axial view before T1ρ fitting. T1ρ pseudo-color images of left (c) and right (d) knees show that there was no significant imaging change of the patella cartilage.

Differences in T1ρ value among different portions within the patellar cartilage. The mean T1ρ values at the upper, central and lower layer portions of the left patella cartilage had significant differences (upper and central: t = 7.668, *P* = 0.000; upper and lower: t = 2.146, *P* = 0.033; central and lower: t = -3.315, *P* = 0.001), the average value of T1ρ was highest at upper portion (Fig 2.). There were obvious differences in the average T1ρ values of the lateral, partial lateral, middle, partial medial and medial portions (F = 7.203, *P* = 0.000), the average value of T1ρ was highest in the lateral portion (Fig 3.). There were also differences in right patella cartilage (upper and central: t = 10.449, P = 0.000; upper and lower: t = 3.579, P = 0.000; central and lower: t = -5.210, P = 0.000), and the average value of T1ρ on right side was also highest at upper portion (Fig. 2). The mean T1ρ values at the lateral, partial lateral, middle, partial medial and medial portions of the right patella cartilage existed differences (F = 3.751,P = 0.005), the average value of T1ρ was highest in the lateral portion on right side, too(Fig. 3).

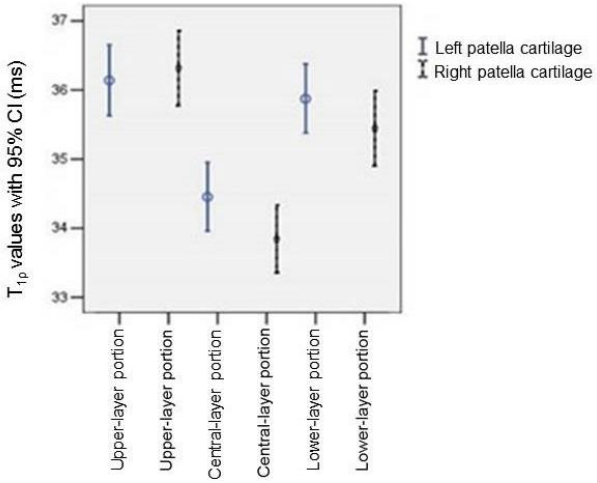

Figure 2. Description of T1ρ values at upper, central and lower layer portions of the bilateral patella cartilage. 95% confidence interval (CI) of mean T1ρ values at upper, central and lower layer portions are shown using an error bar. In Table 2, mean T1ρ values and 95% CI are shown.

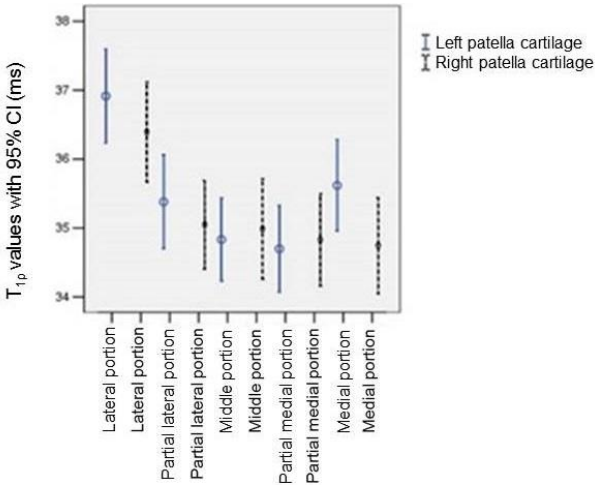

Figure 3. Description of T1ρ values at lateral, partial lateral, middle, partial medial and medial portions of the bilateral patella cartilage. 95% confidence interval (CI) of mean T1ρ values at lateral, partial lateral, middle, partial medial and medial portions are shown using an error bar. In Table 2, mean T1ρ values and 95% CI are shown.

T1ρ values were no difference between corresponding ROIs in left and right knees (*P* > 0.05), except the central layer-lateral region(t = 2.426,*P* = 0.019), central layer-medial region(t = 2.549, *P* = 0.014)and lower layer-medial region(t = 2.173, *P* = 0.035).

IV. DISCUSSION

Presently, considerable efforts have been in search of non-invasive techniques to sensitively and accurately

detect biochemical changes prior to the morphologic alterations in articular cartilage [1, 2]. Therefore, in this study, we intend to investigate whether T1ρ MRI could be used as a means to assess early degeneration of articular cartilage in clinical diagnosis. It has been well documented that T1ρ imaging might be used to quantify the biochemical changes in articular cartilage, such as detecting a gradual loss of proteoglycan (PG) [3]. The main manifestations of early degeneration of articular cartilage involves the loss of PG in cartilage matrix, degeneration of collagen and the increase of water content. These microcosmic changes of biochemical structures occur before morphological change [4, 5]. Among which, a loss of PG content is the initial factor and important symbol of the early degeneration of cartilage, and gradually leads to irreversible morphological degeneration of cartilage [6, 7]. Therefore, early degeneration of articular cartilage can be discovered by detecting the content of PG in time [8, 9].

T1ρ MRI is the international research hotspot of bone and joint imaging. T1ρ relaxation time, namely the spin-lattice relaxation in the rotating frame, is used as parameters for assessment, since interaction of energy and proton of hydrone and macromolecule in low frequency of living body can be reflected, and to detect space variation of relaxation time of macromolecule, as a result, T1ρ imaging pcolor could be created. In a word, hydrone with limitation of motion fuses into matrix macromolecule and move slowly, there is an exchange of hydrogen proton and energy between them, and thus, longitudinal relaxation time is T1ρ value [10, 11]. Consequently, T1ρ imaging technology is mainly used to evaluate tissues with the activity of existing hydrone and low frequency macromolecule, such as brain tissue, cartilago articularis, intervertebral disc, and so on [12, 13]. PG polymer of macromolecule in the above mentioned tissues can be fused with hydrone through hydrophilic group and have interaction, therefore, the change of PG content can be objectively reflected by T1ρ value, i.e., the loss of PG leads to an increase in T1ρ value, the increase of T1ρ value reflects that there is a decrease in PG content [10, 11]. In addition, animal studies and the pilot trial had already indicated that the increase of T1ρ value reflected the occurrence of early degeneration of cartilage, and which were in direct proportion to the degree of cartilage degeneration [14].

In the present study, we designed to objectively evaluate the clinical value of T1ρ imaging in diagnose of early articular cartilage degeneration, therefore, we chose patella cartilage of young population as the survey object. The main reasons are as follows: firstly, the patella cartilage is the thickest articular cartilage in human body, the maximum thickness can be 7 mm, so it is convenient for us to observe and measure; secondly, the degeneration of patella cartilage, which caused by frequent curvature movement of knee joint and long-term load bearing of huge lever stress [15], is the most likely and earliest to occur. In this study, subjects underwent conventional PDWI to exclude advanced degeneration of cartilage, but in consideration of the insensitivity of detecting early degeneration of cartilage by using conventional MRI, it was hypothesized that early degeneration of patella cartilage had already occurred in the participants. It was because that subjects range in age from 20 to 35, which have already progressed to the stage of physiological degeneration of cartilage. In human being, the spontaneous degeneration of articular cartilage occurs on the surface layer of bearing area before 20 years old, and without clinical symptoms [16]. The main characteristic is change in biochemical composition on molecular level such as loss of PG in cartilage and so on. The morphological changes are not presented simultaneously, and external biomechanics factors can accelerate the development tendency. Such as this kind of spontaneous degeneration, that without joint symptoms, is popular in population aged from 20 to 40 years [17] old. Therefore, it was safe to assume that all the subjects in this study were at the initial stage of articular cartilage degeneration while the microstructural changes were not detected in conventional MRI, however, we could evaluate the biochemical changes of early degeneration by using T1ρ imaging. Despite all the rhetoric, such speculations surely warrant further investigation. The results of this study could help verify the above hypothesis: there were regional increase in T1ρ value of patellar cartilage, and which reflected that there were early regional degeneration in patella cartilage. It was obvious that the application of T1ρ imaging in quantitative analysis on patella cartilage of young population in this study has a strong scientific and practical significance, which was also conductive to discuss the influence factor and occurrence regularity of early degeneration of patella cartilage.

It has been well documented that the uneven bearing distribution of cartilage, which means the overload occurs in regional area, leads to the decrease of PG content, and this is the main external factor of cartilage degeneration [18]. Based on the results of this study, our findings can provide evidence for the above point of view: there were regional differences in T1ρ value at different portions of bilateral patella cartilage, and stress imbalance leads to the formation of regional degeneration of patella cartilage.

In this study, we found that T1ρ values showed a most significant increase at the upper and lateral portions, which suggested that the degeneration degree of upper and lateral portions were more than that of other portions. The findings could be explained by the hypothesis that the facies medialis of patella cartilage is non-habitual contact region, the contact only exists when buckling action of knee joint is more than 120°, thus, it rarely bears stress action during the normal activities [18], and the upper layer and facies lateralis of patella cartilage are the main loading regions of stress for bearing and buckling actions of knee joint, especially, the upper layer of patella cartilage, which act as the fulcrum of lever effect of reciprocating flexion and extension for the whole knee joint, bears long-term huge

load [15]. Therefore, the upper layer and lateral portions of patella cartilage has the severest degeneration under the action of high stress, and there was a significant increases in the loss of PG at these portions, while the ultra-structural alterations were reflected by the sensitive T1ρ values. Obviously, because of the influence of anatomical structure on stress load of patella cartilage, there is a correlation between cartilage degeneration and anatomic site.

V. CONCLUSION

In conclusion, the main contribution of this study lay in the application of T1ρ imaging to quantitatively reflect the minimal changes of proteoglycan before the morphologic alterations within patellar cartilage. The results suggested that T1ρ imaging can be potentially used as a clinical scale for quantitatively characterizing early cartilage degeneration in knees. Therefore, T1ρ imaging seems to be the most promising molecular imaging technology and has some more applied value in the world today, and hopeful to become quantitative index of imaging diagnosis in articular cartilage degeneration.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Hao Wang, Si Shen and Zhao-Jia Liang contributed equally to this work, as the same first author. Hao Wang: Study concept and design; preparation of study samples; reading the MRI scans and acquisition of data; statistical analysis; drafting of the manuscript; final approval of the version to be published. Si Shen: Study concept and design; preparation of study samples; reading the MRI scans and acquisition of data; analysis and interpretation of data; statistical analysis; revising manuscript critically for important intellectual content; final approval of the version to be published. Zhao-Jia Liang: Preparation of study samples; statistical analysis; drafting of the manuscript; final approval of the version to be published. Hao Lu: Statistical analysis; drafting of the manuscript; final approval of the version to be published. Jing Zhang: Preparation of study samples; reading the MRI scans and acquisition of data; final approval of the version to be published. Ci-Ci Zhang: Reading the MRI scans and acquisition of data; final approval of the version to be published. Fei Wang: Analysis and interpretation of data; final approval of the version to be published. All authors read and approved the final manuscript.

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