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Original Article

Evaluation of age-related changes in lumbar facet joints using T2 mapping

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ABSTRACT

Background: The purpose in this study is to investigate the T2 value of lumbar facet joint (FJ) in subjects without lumbar spinal disorders, age from 20s to 70s, using T2 mapping, and to evaluate the correlation between age and T2 value. And also, we investigated the T2 value of lumbar intervertebral disc (IVD) in the same way as FJ, and evaluated the correlation between the T2 value of FJ and that of IVD.

Methods: We investigated 60 volunteers (30 male, 30 female), who were recruited from six age groups, 20s–70s (10 subjects in each decade; 5 male, 5 female). We measured the T2 values of FJ at the L4/5 level in axial image and those of IVD (nucleus pulposus; NP, anterior and posterior annulus fibrosus; AAF and PAF) at the L4/5 level in midline sagittal image. We investigated the correlation between age and T2 value of FJ, and the correlation between the T2 value of FJ and that of IVD.

Results: There was a strong positive correlation between age and T2 value of FJ ($r = 0.717$). Age and T2 values of IVD were negatively correlated (NP; $r = -0.728$, AAF; $r = -0.696$, PAF; $r = -0.580$). There was a negative correlation between T2 value of FJ and that of IVD (NP; $r = -0.575$, AAF; $r = -0.617$, PAF; $r = -0.492$).

Conclusions: T2 value of FJ was significantly increased as age rose. Our results suggest that T2 mapping could detect the degenerative changes of FJ related to aging even in subjects without lumbar spinal disorders. The results of this study will be the reference data of FJ T2 value in order to evaluate the relationship between low back pain and FJ using T2 mapping.

1. Introduction

Low back pain (LBP) is one of the most frequent symptoms [1,2], and so there are a lot of opportunities to examine patients with LBP in clinic. The number of patients suffering from LBP is very high all over the world, and so LBP is a serious problem affecting medical economy [1,3]. According to the data from comprehensive survey of living conditions, 2013 in Japan, which has been performed by Ministry of Health, Labor and Welfare in our country, the complaining ratio of the LBP was approximately 9.2% in male (92.2 per 1000 people), and 11.8% in female (118.2 per 1000 people) [4]. In the past, many research on causes of LBP have been conducted, and it is widely accepted that degeneration of the lumbar facet joint (FJ) is one of the main causes of LBP [1–3,5,6]. However, unclear points remain for details about the pathology of FJ.

To evaluate degeneration of FJ, magnetic resonance imaging (MRI) is an indispensable modality. However, it is difficult to quantitative assessment using MRI in conventional imaging procedure [7]. In recent years, improvement of MRI led to the development of quantitative imaging techniques [8–11]. T2 mapping is one of useful method of MRI for clinical quantitative imaging of articular cartilage [1,12,13]. Most of the previous reports on T2 mapping in limb joints studied large joints such as knees [10,11,14,15]. On the other hand, as concerns with the field of spine, studies on lumbar intervertebral disc (IVD) accounted for much [5,6,16–20]. Assessment of T2 values of degenerated IVDs and relevance of LBP to T2 values of IVDs were reported in several peer-reviewed literature [5,6]. But, there are few reports on the research of FJ using T2 mapping [1,12,13]. Furthermore, as far as we know,

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there is no report that T2 values of FJ in subjects without lumbar spinal disorders, who were divided into age groups, were investigated using T2 mapping. In order to conduct research to evaluate the relationship between LBP and FJ using T2 mapping, we consider that it is necessary to investigate T2 values of FJ in subjects without lumbar spinal disorders as reference T2 values before that.

Therefore, the purposes of our study were to investigate the T2 value of lumbar FJ in volunteers using T2 mapping, and to evaluate the correlation between age and T2 value. We consider that the T2 value of lumbar FJ in volunteers will be the reference data of FJ T2 value for further research of FJ using T2 mapping. And also, in order to compare with FJ, we investigated the T2 value of lumbar IVD in the same way as FJ, and evaluated the correlation between the T2 value of FJ and that of IVD.

2. Materials and methods

2.1. Subjects

This study was approved by our institutional review board, and written informed consent was obtained from each subject before enrollment in the study. We posted flyers about this study in our hospital to recruit volunteers. The exclusion criteria were: 1) history of diagnosis of lumbar spine disease, 2) previous surgical history for spinal disease, 3) low back pain at the time of recruitment with Numerical Rating Scale (NRS) > 3, 4) rheumatoid arthritis or other inflammatory disease, 5) infection, 6) neoplastic disease, 7) remarkable lumbar spine degeneration, 8) contraindications for MRI, or 9) during pregnancy. Sixty participants (30 male, 30 female) were included. Volunteers were recruited from six age groups: 20–29 years (20s); 30–39 years (30s); 40–49 years (40s); 50–59 years (50s); 60–69 years (60s); and 70–79 years (70s). Each group had 10 volunteers (5 men, 5 women). Among these volunteers, there were just normal subjects and patients as well. No patients were diagnosed with lumbar spine disease in volunteers. Seven male volunteers in 50s–70s were patients with rotator cuff injury, and one male volunteer in 60s was patient with finger tendon injury. Other volunteers are just normal subjects. The definition of remarkable lumbar spine degeneration is grade 2 and 3 of MRI grading system of Weishaupt, which is criteria for grading osteoarthritis of FJ. In this study, volunteers whose FJ with grade 2 and 3 were not included. In this study, the definition of subjects without lumbar spinal disorders was that there were no history of diagnosis of lumbar spine disease and treatment, and there were no neurological symptoms and LBP with NRS >3. We regarded the subjects who answered “yes” against this question “Do you feel low back pain (LBP) with NRS > 3 for 3 months your daily life?” were subjects LBP. We excluded these subjects. All volunteers underwent MRI of the lumbar spine, and no volunteers interrupted MRI for feeling ill.

2.2. Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

2.3. MRI protocol and image analysis

MR imaging was performed with a 3.0 T MR unit (MAGNETOM Skyra; Siemens, Erlangen, Germany) that had a gradient strength of 45 mT/m and with use of a phased-array spine coil. The imaging protocol consisted of axial and sagittal planes, multi-echo spin-echo T2-weighted sequence performed with the following parameters: repetition time msec/echo time msec, 1500/15, 30, 45, 60, 75, and 90; field of view, 200 × 200 mm; pixel matrix, 128 × 128; voxel size, 1.6 × 1.6 × 3.0 mm; bandwidth, 200 Hz/pixel; one signal acquired; six sections; and total acquisition time, 3 min 54 s. T2 relaxation times were obtained from online reconstructed T2 maps by using a pixelwise, monoexponential nonnegative least-squares fit analysis (MapIt; Siemens Medical Solutions, Erlangen, Germany) [15].

We obtained axial and sagittal T2-weighted cross-sectional images of L4/5 level. Of axial images, imaging cut sequences were at least 3 mm, using the way described by Williams et al. [21], and we selected one demonstrating most closely bisected the FJs at L4/5 level. Of sagittal images, we selected a midline sagittal image at L4/5 level. From selected axial and sagittal images, T2 map images were created. The regions of interest (ROIs) were set manually by an author (SE). ROIs for FJs were drawn on axial first echo image across the area including the joint space (Fig. 1A), and copied onto the T2 map images (Fig. 1B), and so T2 values of FJs were measured automatically. To measure T2 values of IVD, we used the way described by Trattnig et al. [22] and Takashima et al. [19]. In sagittal view, IVD at L4/5 was divided into five equal areas, designating the front fifth of the anterior annulus fibrosus (AAF), the middle fifth of the nucleus pulposus (NP), and the last fifth of the posterior annulus fibrosus (PAF). ROIs for IVDs were drawn on sagittal first echo image across the area including AAF, NP and PAF (Fig. 2A), and copied onto the T2 map images (Fig. 2B), and so T2 values of IVDs were measured automatically. We measured the T2 values of FJs for both right and left sides at the L4/5 level in axial image and those of IVD (AAF, NP and PAF) at the L4/5 level in midline sagittal image.

2.4. Statistical analysis

The statistical evaluation was performed using Statcel 4 (Statcel - The Useful Addin Forms on Excel - 4th ed.). We investigated the following items as the background of volunteers, 1) body height, 2) body weight, 3) body mass index (BMI), 4) NRS of LBP. Subsequently, we also statistically investigated the correlation between age and T2 value of FJ, between age and T2 value of IVD, and then, between T2 value of FJ and that of IVD using Pearson's rank-correlation coefficient. We calculated the mean T2 value of the right and left FJs, and used the value for our study. The strength of association was determined by considering the correlation coefficients and their significance. A correlation was considered very strong if there was an absolute value of 0.80–1.00, a strong correlation by 0.60–0.79, a moderate correlation by 0.40–0.59, a weak correlation by 0.20–0.39, and no correlation by an absolute value under 0.20. A p-value of less than 0.05 was considered statistically significant.

3. Results

3.1. Demographic volunteers data

The mean age was 48.8 years (23–79 years), and by age grouping, 26.2, 32.7, 42.0, 54.6, 64.0, 74.0 years in 20s-70s, respectively. There was no statistically significant correlation between age and body height ($r = -0.230$, $P = 0.077$) (Fig. 3A), body weight ($r = -0.016$, $P = 0.906$) (Fig. 3B), body mass index (BMI) ($r = 0.207$, $P = 0.113$) (Fig. 3C), or NRS of LBP ($r = -0.189$, $P = 0.147$).

3.2. T2 values of lumbar FJ and IVD

Table 1 shows T2 values of lumbar FJ and IVD (AAF, NP, PAF). T2 values are given as mean ± standard deviation. We calculated the

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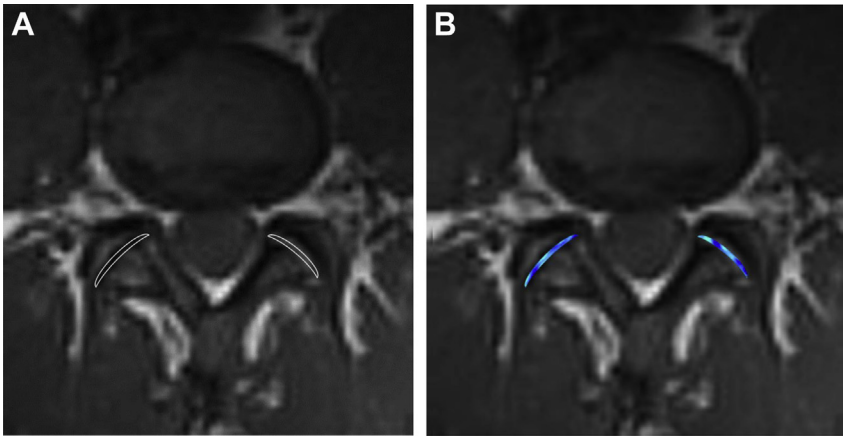

Fig. 1. The regions of interest (ROIs) for lumbar facet joints (FJs) at L4/5 were drawn on axial first echo image across the area including the bilateral joint space (A), and copied onto the T2 map images (B).

mean T2 value of the right and left FJs, and used the value for our study.

3.3. Correlation between age and T2 value of FJ

There was a strong positive correlation between age and T2 value of FJ ($r = 0.717$, $P < 0.0001$) (Fig. 4). T2 value of FJ was significantly increased as age rose.

3.4. Correlation between age and T2 value of IVD (AAF, NP, PAF)

There was a strong negative correlation between age and T2 value of AAF ($r = -0.728$, $P < 0.0001$) (Fig. 5A), NP ($r = -0.696$, $P < 0.0001$) (Fig. 5B), and a moderate negative correlation between age and T2 value of PAF ($r = -0.580$, $P < 0.0001$) (Fig. 5C). T2 value of IVD was significantly decreased as age rose.

3.5. Correlation between T2 value of FJ and that of IVD (AAF, NP, PAF)

There was a strong negative correlation between T2 value of FJ and that of AAF ($r = -0.617$, $P < 0.0001$) (Fig. 6A), and a moderate negative correlation between T2 value of FJ and that of NP ($r = -0.575$, $P < 0.0001$) (Fig. 6B), PAF ($r = -0.492$, $P < 0.0001$) (Fig. 6C). T2 value of FJ was significantly increased as T2 value of IVD decreased.

3.6. Correlation between NRS of LBP and T2 value of FJ and IVD (AAF, NP, PAF)

There was no statistically significant correlation between NRS of LBP and T2 value of FJ ($r = 0.067$, $P = 0.612$). On the other hand, there was a weak negative correlation between NRS of LBP and T2 value of IVD-AAF ($r = -0.291$, $P = 0.024$), IVD-NP ($r = -0.381$, $P = 0.003$), and IVD-PAF ($r = -0.389$, $P = 0.002$).

4. Discussion

T2 mapping is one of useful modalities for clinical quantitative imaging of articular cartilage and IVD [1,12]. It allows quantification of water content and collagen orientation by measuring T2 values, and can be used to detect degeneration of tissue in cartilage and IVDs occurring in the early stage [8,9]. T2 values are dependent on the integrity of collagen sequence, and the quantity of water and proteoglycan content [8,9].

The FJ is a synovial joint, and so the joint surface is covered by hyaline cartilage and has a joint capsule [2,23]. The structure is similar to joints of limbs, such as the knee joint, and also osteoarthritis of the FJ is similar to that of joints of limbs [2,23]. Therefore, it is predicted that changes in T2 values with degeneration of FJs would be similar to those with degeneration of cartilage in knee joints [12,13]. The previous studies on T2 mapping regarding knee joint

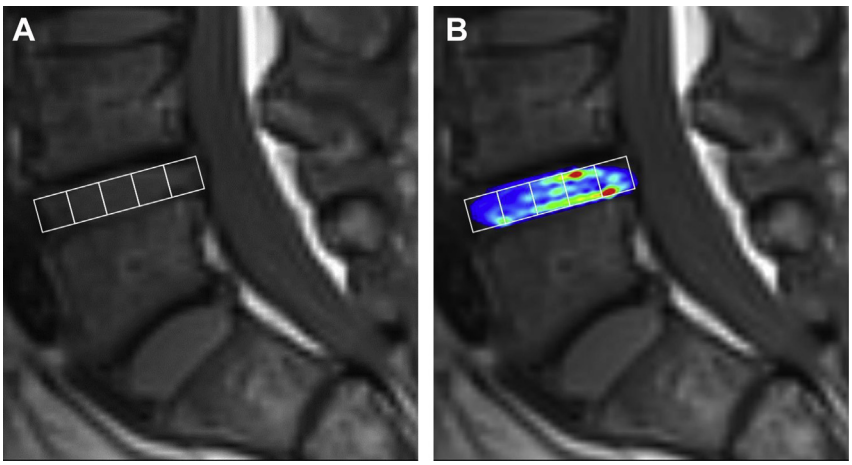

Fig. 2. The regions of interest (ROIs) for lumbar intervertebral disc (IVD) at L4/5 were drawn on sagittal first echo image across the area including the front, middle, and last fifth (A), and copied onto the T2 map images (B).

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demonstrated higher T2 values in degenerative cartilage compared to healthy knee joints [14]. Compositional changes in water content and collagen sequence of the matrix of cartilage can be evaluated quantitatively using T2 mapping. T2 values reflect the integrity of collagen sequence, the quantity of water and proteoglycan content, and the mobility of protons in water molecules in collagen matrix [8,9]. Therefore, T2 values of degenerative cartilage increase due to the collapse of collagen sequence, the increase in water content, and increased mobility of protons in water molecules in collagen matrix [8,9,12]. On the other hand, T2 values of normal cartilage do not increase because the mobility of protons is restricted due to the dense and regular collagen matrix.

Takashima et al. [13] evaluated lumbar FJ in group with lumbar degenerative spondylolisthesis (DS) and non-spondylolisthesis (NS) by T2 mapping, and reported that T2 values of FJ were significantly higher in the DS than NS group. They considered that water content increased as a results of degeneration in the FJ and that T2 value increased significantly in the DS group. Stelzeneder et al. [12] evaluated the relationship between LBP and T2 value of FJ by using T2 mapping. They compared 10 patients (the mean age was 31.5, range 20–50) suffering from acute or chronic LBP and 5 asymptomatic volunteers (the mean age was 25.4, range 23–28). In their results, there was no difference in T2 value of FJ between patients with LBP and asymptomatic volunteers. They assessed the results that their subjects' age was relatively young, so degenerative changes of FJ did not advance. In another report [24], it was stated that FJs osteoarthritis is uncommon before the age of 45 years. Considering their discussion, we speculate that there is no difference in T2 value of FJ between patients with LBP and volunteers only for the young generation, but there will be a difference in T2 value of FJ for elderly generation. As far as we know, there is no study to investigate T2 values of FJ in elderly generation volunteers using T2 mapping. This study is a first article to investigate age-

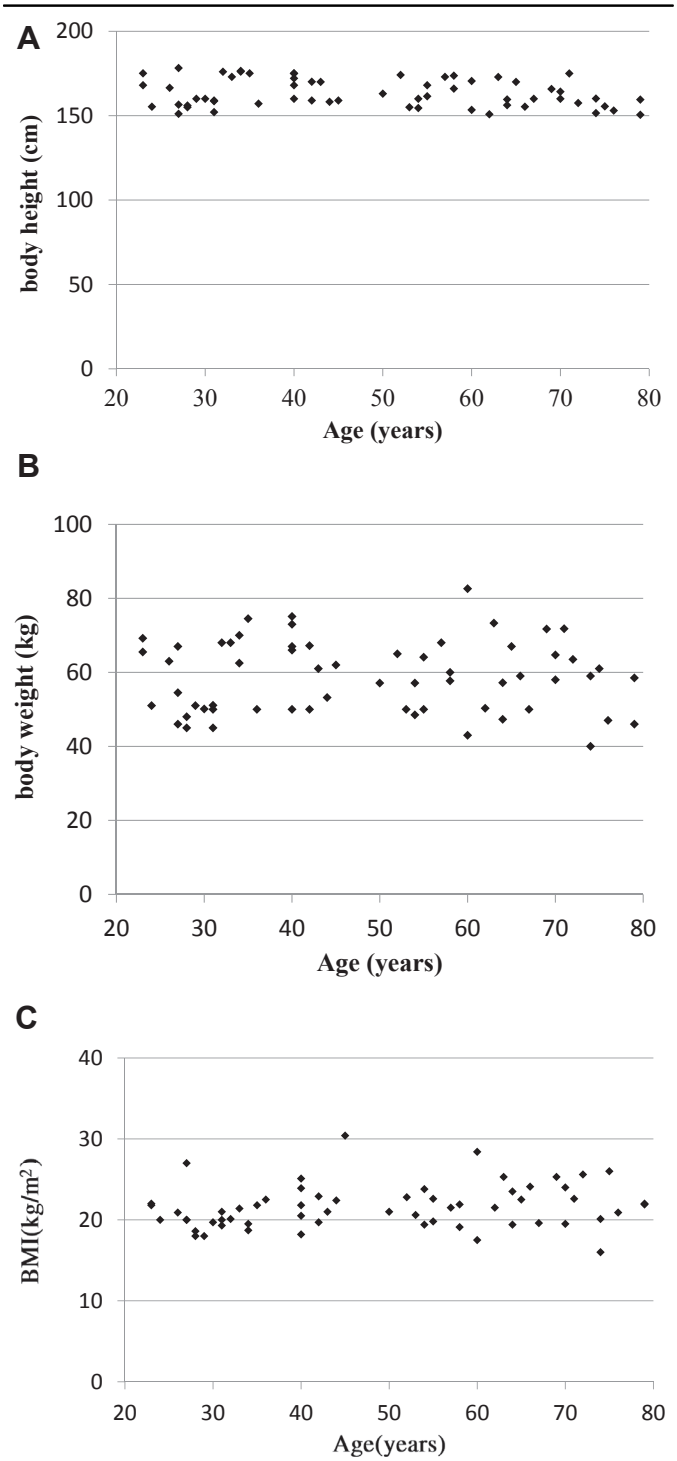

Fig. 3. The correlation between age and body height (A), body weight (B), body mass index (BMI) (C).

Table 1
T2 values of lumbar facet joint and intervertebral disc.

Age	T2 values (msec)			
	FJ	IVD-AAF	IVD-NP	IVD-PAF
20s	79.5 ± 8.2	99.8 ± 14.9	171.2 ± 47.4	155.5 ± 51.5
30s	78.6 ± 5.2	99.6 ± 28.3	155.9 ± 56.8	145.9 ± 76.5
40s	91.6 ± 11.5	73.1 ± 16.8	106.1 ± 39.9	95.9 ± 46.4
50s	98.4 ± 17.3	62.9 ± 16.9	81.4 ± 25.4	80.1 ± 33.1
60s	109.3 ± 12.0	58.1 ± 16.5	72.7 ± 19.5	71.5 ± 16.2
70s	111.8 ± 10.9	50.2 ± 8.5	74.8 ± 15.9	71.9 ± 18.4

T2 values are given as mean ± standard deviation.
We calculated the mean T2 value of the right and left FJs, and used the value for our study.
FJ: Facet joint.
IVD: Intervertebral disc.
AAF: Anterior annulus fibrosus.
NP: Nucleus pulposus.
PAF: Posterior annulus fibrosus.

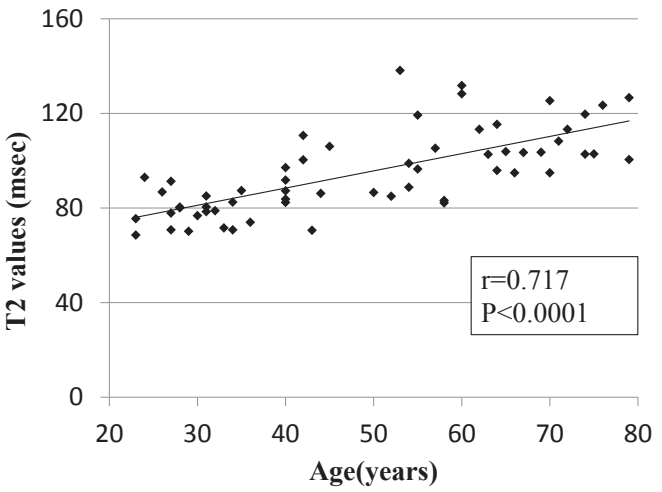

Fig. 4. The correlation between age and T2 value of lumbar facet joint (FJ). We calculated the mean T2 value of the right and left FJs, and used the value for our study.

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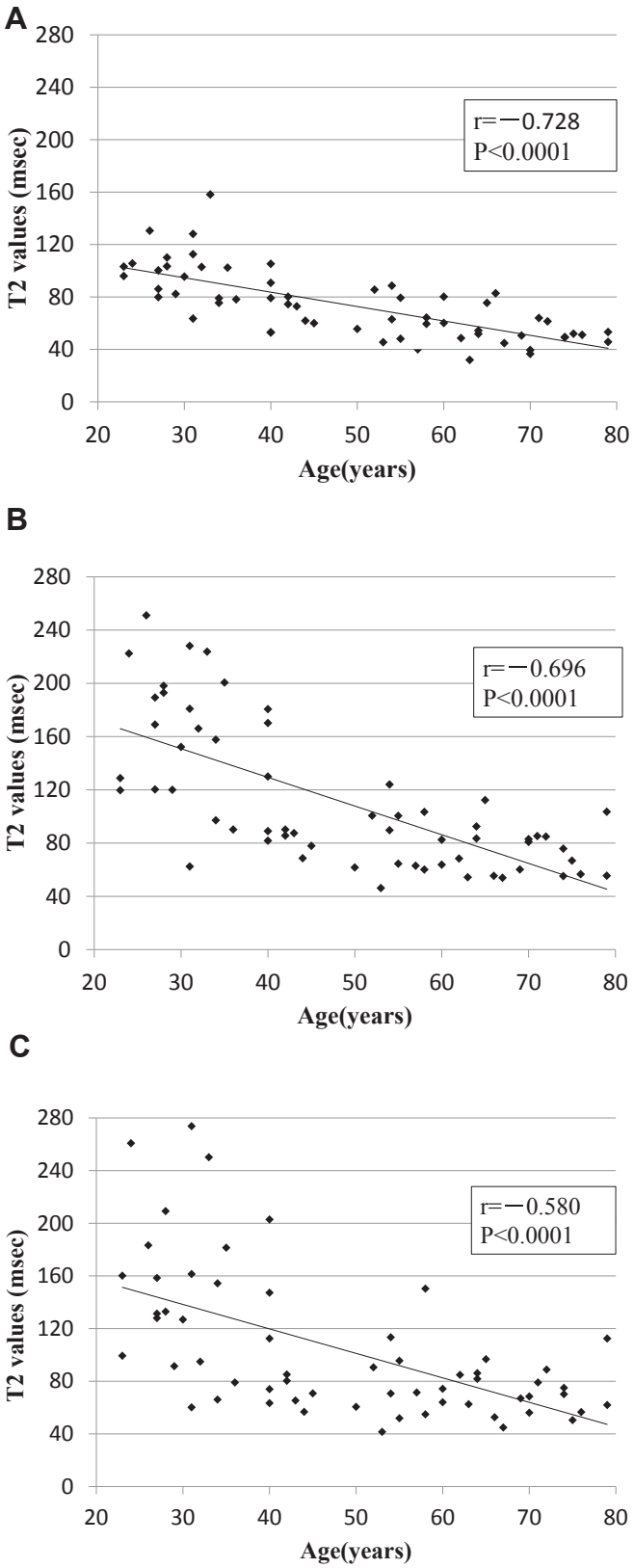

Fig. 5. The correlation between age and T2 value of lumbar intervertebral disc (IVD)-anterior annulus fibrosus (AAF) (A), nucleus pulposus (NP) (B), posterior annulus fibrosus (PAF) (C).

related changes in T2 value of FJ for volunteers from young to elderly generation using T2 mapping.

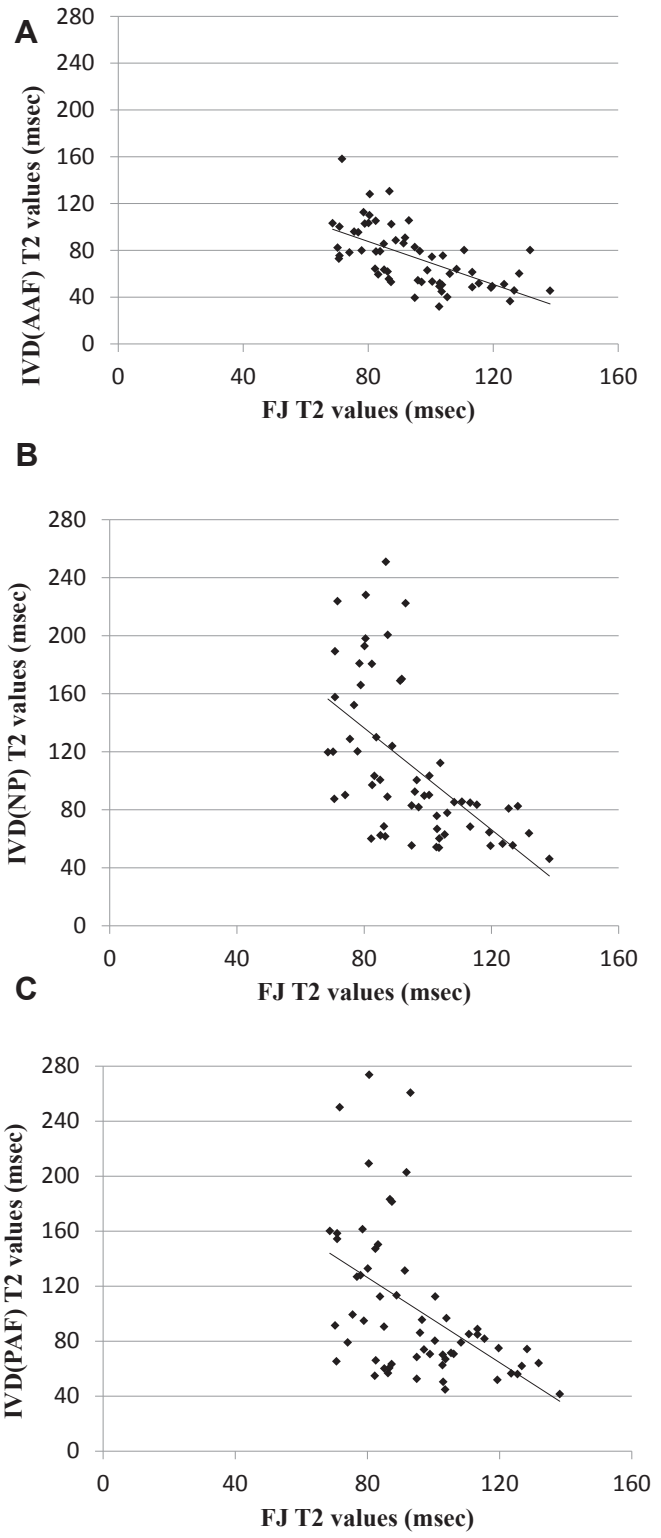

Fig. 6. The correlation Between T2 Value of lumbar facet joint (FJ) and that of intervertebral disc (IVD)-anterior annulus fibrosus (AAF) (A), nucleus pulposus (NP) (B), posterior annulus fibrosus (PAF) (C).

Several studies on LBP and IVD using T2 mapping have been reported, but few studies on LBP and FJ using it have been reported. The report of Stelzeneder et al. is an only article to evaluate about the relationship between LBP and T2 value of FJ. We consider that T2 mapping is a useful method of MRI for evaluating LBP originating FJ,

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just as it is to evaluate LBP originating IVD. In order to evaluate the relationship between LBP and FJ using T2 mapping, it is necessary to investigate T2 values of FJ in normal lumbar vertebra as reference T2 values before that. In this study, we calculated T2 value of lumbar FJ in volunteers, age from 20s to 70s, using T2 mapping. We consider that the data of Table 1 will be the reference data of FJ T2 value for further research of FJ using T2 mapping. Because, as far as we know, there is no report that T2 values of FJ in subjects without lumbar spinal disorders, who were divided into age groups, were investigated using T2 mapping. To obtain the reference data of FJ T2 value is another object of this research. We estimate that this makes it possible to evaluate T2 value of patients with LBP in more detail.

The current study demonstrated a strong positive correlation between age and T2 value of FJ. T2 value of FJ was significantly increased as age rose. Our results suggest that T2 mapping could detect the degenerative changes of FJ related to aging even in subjects without lumbar spinal disorders. To our best knowledge, there has been no reports investigating the relationship between age and T2 value of FJ, and the age of the subject was not taken into consideration. Therefore, there are variations in T2 value of FJ among previous reports. We emphasize it important to compare with subjects with same age generation in the study of lumbar FJ or IVD using T2 mapping.

There are some limitations in this study. Firstly, the accuracy of calculation methods of T2 values was uncertain. ROIs were selected manually by an author, and it was difficult to draw ROIs if MRI image was poor resolution, especially articular surfaces of FJs. Secondly, the influence of facet effusion on T2 value of FJ is still controversial. The solution to the influence of facet effusion is not mentioned in other peer-reviewed literature. In this study, there were no volunteers who admitted facet effusion with axial T2-weighted cross-sectional images of L4/5 level by chance. We consider that lumbar spine degeneration in the early stage without facet effusion is a good indication for T2 mapping. Thirdly, we did not evaluate the degree of degeneration of lumbar spine with plain radiographs and CT scan. We evaluated degeneration of FJ with only MRI. Because the subjects are volunteers, we did not obtain plain radiographs and CT scan, considering the risk of radiation exposure. And finally, we included subjects with no history of diagnosis of lumbar spine disease, symptoms and treatment in this study. In the future study, we will include patients with lumbar degeneration with symptoms such as LBP and lower extremity pain.

In conclusions, our results suggest that T2 mapping could detect the degenerative changes of FJ related to aging even in subjects without lumbar spinal disorders. The results of this study will be the reference data of FJ T2 value in order to evaluate the relationship between LBP and FJ using T2 mapping.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgments

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