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Preliminary study on diagnosis of lumbar disc degeneration with magnetic resonance T1p, T2 mapping and DWI quantitative detection technologies

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Abstract. – OBJECTIVE: The value of diagnosing lumbar disc degeneration with T1p magnetic resonance imaging (MRI), T2 mapping and diffusion-weighted imaging (DWI) technologies.

PATIENTS AND METHODS: We selected 30 patients diagnosed with lumbar disc herniation (group A), 30 patients with lumbar disc degeneration (group B) and 30 healthy volunteers (group C) and carried out Pfirrmann grading of intervertebral discs (L1-S1 segment) based on conventional T2WI median sagittal images. T1p, T2 mapping and DWI were then applied.

RESULTS: Group A primarily had Pfirrmann grades of III-IV, group B had Pfirrmann grades of I-IV and group C had Pfirmann grades of I-II. The differences between the groups were statistically significant (p <0.05). The average T1p, T2 mapping and apparent diffusion coefficient (ADC) values of the nucleus pulposus and annulus fibrosus in group A were significantly lower than in group B. The highest values were in group C, and the differences were statistically significant (p <0.05).

CONCLUSIONS: T2WI, T1p MRI, T2 Mapping and DWI technologies have different capacities to diagnose lumbar disc degeneration, and have great value in improving diagnostic accuracy.

Key Words
Magnetic resonance imaging; T1p, T2 Mapping, DWI, Lumbar disc degeneration, Pfirrmann grading.

Introduction

Intervertebral disc degeneration (IVDD) is the leading cause of lower back pain in the elderly, and apart from age, is related to labor, posture, systemic diseases and genetic factors. Magnetic resonance imaging (MRI) is the preferred method of diagnosis of IVDD, as it can provide information on the protrusion of intervertebral discs, Schmorl nodules, Modic changes and apophysis formation, among other parameters[1]. In conjunction with the Pfirrmann grading system[2], it is of great value in guiding treatment and observations during follow-up. The Pfirrmann grading system is based on the four elements of sagittal T2WI images, i.e. nuclear structure, the boundary between the nucleus pulposus and the annulus fibrosus, signal strength of the nucleus pulposus and height of the lumbar disc nucleus. It provides several advantages including being intuitive, simple and correlates with the severity of clinical symptoms[3]. However, given that the grading system is based on signal strength, it is greatly affected by the scanning parameters and is subjective. Additionally, there will always be differences in the level of definition[4]. Therefore, quantitative, objective and reproducible detection methods are urgently needed. The combined application of proteoglycan (PG) content related T1p imaging, water content related T2 mapping imaging and DWI, related to both PG and water, has potential value[5] in improving diagnostic sensitivity and accuracy. The present study provides a reference for clinical diagnosis and treatment of lumbar disc degeneration using MRI.

Patients and methods

Patients

We selected 30 patients diagnosed with lumbar disc herniation (group A), 30 patients with lumbar disc degeneration (group B) and 30 healthy volunteers (group C) in our hospital from January 2015 to January 2016. The exclusion criteria inclu-

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ded: traumatic lumbar spine lesions, pathological lumbar spine lesions such as bone tumor, spinal tuberculosis, spinal canal stenosis, compound spinal cord injury, lower extremity peripheral artery disease or neuropathy, vascular disease, systemic diseases such as autoimmune disease or diabetes mellitus, pregnancy, breast-feeding women, unacceptable MRI and poor compliance. The study was approved by the Ethics Committee of our Hospital and we obtained informed consent from patients and their families. There were 18 males and 12 females in group A, aged 46-73 years old, with an average age of 58.2 ± 14.3 years; there was a total of three L1-2 segment lesions, six L2-3 segment lesions, 14 L3-4 segment lesions, five L4-5 segment lesions and two L5-S1 segments lesions. There were 17 males and 13 females in group B, aged 43-76 years old, with an average age of 56.9 ± 12.8 years; there was a total of two L1-2 segment lesions, five L2-3 segment lesions, 13 L3-4 segment lesions, seven L4-5 segment lesions and three L5-S1 segment lesions. There were 16 males and 14 females in group C, aged 42-78 years old, with an average age of 57.6 ± 12.5 years. There were no statistically significant differences in age, gender or segment lesions between group A and group B ($p > 0.05$).

Imaging

For all patients, Pfirrmann grading of intervertebral disc degeneration was carried out based on conventional T2WI median sagittal images. After which, T1p MRI, T2 mapping and DWI methods were applied.

Conventional T2WI scanning: A 3.0T magnetic resonance imaging system (3.0T HDX, GE, Buckinghamshire, UK) with a dedicated coil (8us Torsopa coil) for the spine was used. Patients were in the supine position and scanned feet-first. The TSE sequence was used. The scanning parameters were: TR = 3000 ms, TE = 128 ms, FOV = 220 mm (FH) × 201 mm (AP) × 55 mm (RL), layer thickness = 5 mm, layer number = 11, matrix = 448 × 448 and flip angle = 90°. Lumbar disc degeneration by Pfirrmann grading is shown in Table I and Figure 1. T1p scanning employed a 3D steady-state gradient echo sequence. The scanning parameters were TR = 4.85 ms, TE = 2.39 ms, FOV = 220 mm (FH) × 201 mm (AP) × 55 mm (RL), layer thickness = 5 mm, layer number = 11, matrix = 448 × 448, flip angle = 50°, spin locking frequency = 500 Hz, time of spin locking = 0/10/20/30/40 ms. T2 mapping scanning parameters were TR = 1162 ms, TE = n × 20 ms, FOV = 220 mm (FH) × 220 mm (AP) × 25 mm (RL), layer thickness = 5 mm, layer number = 5, matrix = 448 × 448, flip angle = 90° and time = 12:41. Before scanning, automatic shimming and fat suppression modules were used in order to reduce constructed defects caused by respiratory and gastrointestinal peristalsis. The saturation belt was set in front of the vertebral body to cover the entire intestinal tract. DWI scanning employed an echo planar imaging pulse sequence. The parameters were: TR = 3000 ms, TE = 64 ms, FOV = 180 mm (FH) × 56 mm (AP) × 65 mm (RL), layer thickness = 5 mm, scanning layer number = 11, matrix = 288 × 288 and flip angle = 90°. Acquisition and processing of the data including T1p values were done using the post-processing software (GE adw4.5 workstation, Buckinghamshire, UK). Image software (NIH) was used to manually trace the regions of interest (ROI) of the nucleus pulposus, carry out pseudo-color processing, image fusion and determine T1p value. The ROI was traced in T2WI images. The intervertebral disc was trisected on the median sagittal layer and the middle region was taken as the ROI to measure the mean (Figure 2).

Table I. Lumbar intervertebral disc degeneration Pfirrmann grading.

Grade	Nucleus pulposus structure	Boundary between nucleus pulposus and annulus fibrosus	Nucleus pulposus signal strength	Intervertebral disc height
I	Uniform, bright white	Clear	High (comparable to cerebrospinal fluid)	Normal
II	Non-uniform, horizontal belt can be provided	Clear	High (comparable to cerebrospinal fluid)	Normal
III	Non-uniform, gray	Obscure	High	Normal to mild, lowered
IV	Non-uniform, gray to black	Disappeared	High to low	Normal to high, lowered
V	Non-uniform, black	Disappeared	Low	Severe, lowered

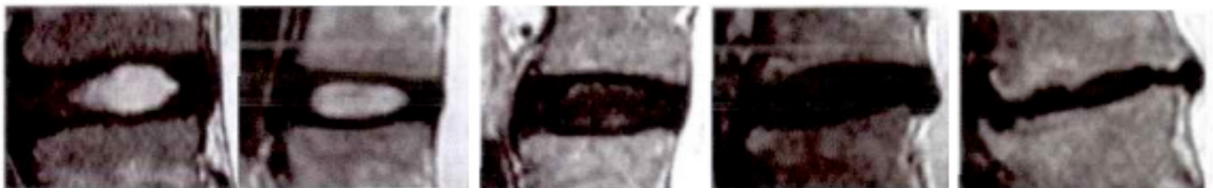

Figure 1. Pfirrmann grading of intervertebral disc degeneration (from left to right: grade I, II, III, IV and V).

Observational Indexes

Differences in Pfirrmann grading of intervertebral discs, and T1p, T2 mapping and apparent diffusion coefficient (ADC) values of the nucleus pulposus and annulus fibrosus were compared.

Statistical Analysis

SPSS20.0 software (SPSS Inc., Chicago, IL, USA) was used for data analysis. Following a normality test, the quantitative data were expressed as mean ± standard deviation, and comparisons between the three groups were by single factor ANOVA. The count data were expressed as number of cases or percentage (%) and the grade data were compared with a rank sum test. $p < 0.05$ was taken as statistically significant.

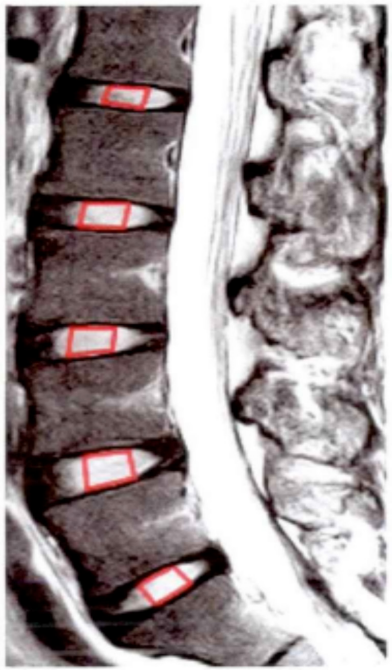

Figure 2. Selection of the T1p region of interest (the intervertebral disc was trisected on the layers with the largest vertical diameter in the middle of the intervertebral disc and the largest anteroposterior diameter of the spinal canal at the rear of the intervertebral disc. The middle region was taken as the region of interest).

Results

Comparison of intervertebral disc degeneration by Pfirrmann grading

Normal intervertebral discs showed homogeneous, high signals on T2WI. Boundaries with the homogeneous, low signals of the surrounding annulus fibrosus were clear and the edges were sharp. The patients in group A had Pfirrmann grades of III-IV, patients in group B had Pfirrmann grades of I-IV and the healthy controls of group C had Pfirrmann grades of I-II. The differences among groups were statistically significant ($p < 0.05$) (Table II).

Comparison of T1p values of the nucleus pulposus and annulus fibrosus

T1p pseudo-color images used color gradations to represent different T1p values. Black to purple represented T1p values from low to high, respectively. In contrast with the uniform internal signals of the nucleus pulposus and annulus fibrosus shown in T2WI images, T1p pseudo-color images displayed the nucleus pulposus divided into the median value region with yellowish green in the outer periphery and the high value region with orange in the core. In addition to blue-colored low values, there were also mixed, partial median value colors. With the decrease in T2WI signal from the nucleus pulposus, it gradually showed a uniform blue color, and the magnitude of the annulus fibrosus was also increased. The mean T1p values of the nucleus pulposus and annulus fibrosus in group A were lower than in group B. The highest values were in group C, and the differences were statistically significant ($p < 0.05$) (Table III).

Comparison of nucleus pulposus and annulus fibrosus T2 mapping values

Concerning the T1p imaging, T2 mapping of the nucleus pulposus core had lower magnitudes. The magnitudes were more uniform in the regions of the nucleus pulposus or annulus fibrosus. With the decreased T2WI signal of the

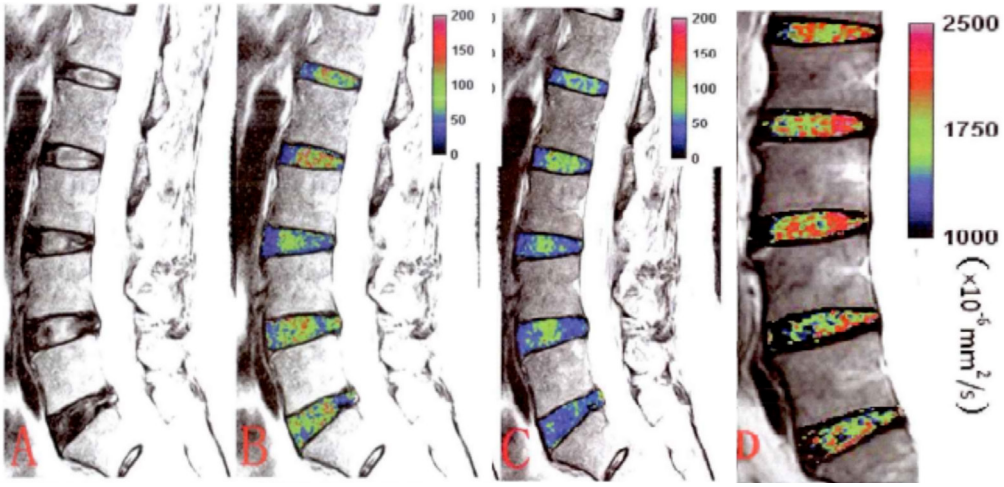

Figure 3. The conventional T2WI (**A**), T1p (**B**), T2 mapping (**C**) and DWI (**D**) pseudo-color fusion image of grade III and IV intervertebral discs. Panel A shows a L5-S1 intervertebral disc at grade IV. The nucleus pulposus signal was black, and its boundary with the annulus fibrosus disappeared. The remaining discs are grade III, the nucleus pulposus signal is gray, its boundary with the annulus fibrosus is unclear. Panel B shows the nucleus pulposus in low value green, and the annulus fibrosus value is increased. Panel C shows the nucleus pulposus in low value green. Both of them demonstrate the same trend. Change in the amplitude of T2 mapping value of the annulus fibrosus was lower than the change in amplitude of the T1p value. Panel D shows the nucleus pulposus in low value green. The T1p and T2 mapping values were higher than the center of the nucleus pulposus, while the high ADC value was mainly located in the rear of the nucleus pulposus and the difference between nucleus pulposus and annulus fibrous was more obvious.

nucleus pulposus, the color of this region gradually showed a uniform blue color and the changes between them were of the same trend. Regarding the T1p imaging, changes in T2 value of the annulus fibrosus were not obvious. The average T2 mapping values of the nucleus pulposus and annulus fibrosus in group A were lower than in group B and the highest values were in group C. The difference were statistically significant (p <0.05) (Table IV).

Comparison of nucleus pulposus and annulus fibrosus ADC values

The pseudo-color images showed there were differences between ADC value distribution within the nucleus pulposus and the distribution of T1p and T2 mapping. The high T1p and T2 mapping values of grade II intervertebral discs were mainly located in the central region of the nucleus pulposus, while the high ADC values were distributed in the edge region of the nucleus pulposus. The difference between the annulus fibrosus and nucleus pulposus was significant (p <0.05). The mean ADC values of the annulus fibrosus and nucleus pulposus in group A were lower than in group B and the highest values were in group C. The differences were statistically significant (p <0.05) (Table V).

Discussion

MRI reflects tissue proton density, moisture content and biological environment. The nucleus pulposus and inner layer of the annulus fibrosus show highlighted signals in MRI. The inner layer of the annulus fibrosus is lower in patients with

Table II. Comparison of lumbar intervertebral disc Pfirrmann grading [rate (%)].

Group category	Case number	I-II	III-IV	V
Group A	30	3 (10.0)	17 (56.7)	10 (33.3)
Group B	30	10 (33.3)	18 (60.0)	2 (6.7)
Group C	30	26 (86.7)	3 (10.0)	1 (3.3)
F			46.710	
p			<0.001	

Note: group A: lumbar disc herniation; group B: degeneration of lumbar intervertebral disc; group C: healthy volunteers.

Table III. Comparison of nucleus pulposus and annulus fibrosus T1p values (ms).

Group category	Nucleus pulposus	Annulus fibrosus
Group A	62.3±20.5	31.4±12.5
Group B	84.7±32.6	55.8±21.6
Group C	112.5±45.8	79.2±36.9
F	21.634	15.649
p	<0.001	<0.001

Table V. Comparison of ADC values of nucleus pulposus and annulus fibrosus (ms).

Group category	Nucleus pulposus	Annulus fibrosus
Group A	1.0±0.2	2.2±0.5
Group B	1.3±0.3	3.4±0.9
Group C	1.7±0.4	6.5±1.2
F	8.524	14.326
p	<0.001	<0.001

IVDD. The annulus fibrosus signal in the inner layer of nucleus pulposus will be reduced with the severity of the degeneration. The difference in signal between the inner and outer layers of the annulus fibrosus will gradually disappear and the height of the intervertebral disc will be low slowly. The final observation is that the T2WI images of intervertebral discs show as a black region of no signal and the collapse of the intervertebral space is slit-shaped[6]. MRI-mediated diagnosis of IVDD has the following advantages[7]: it can assess several parameters of the tissue and generate more imaging data; the diagnostic accuracy is high; it can clearly identify the annulus fibrosus, nucleus pulposus, endplate cartilage and other structures; multi-planar imaging can be achieved directly; quantitative MRI can detect early degeneration and there is no exposure of the patient to radiation. The Pfirrmann grading system is based on the symptoms of patients with average age of 40 years old. It is less effective for early degeneration and intervertebral disc degeneration in elderly patients. Additionally, there may be large discrepancies among graders. In the present study, the patients in group A had Pfirrmann grades of III-IV, the patients in group B had Pfirrmann grades of I-IV and healthy subjects of group C had grades of I-II. The differences among groups were statistically significant.

T1p imaging can achieve spin locking through the "frequency scanning" tuning pulse, after applying the spin locking pulse with different amplitudes. The magnetic moment parallel to the longitudinal axis will be under attenuation, synchronously with the effective magnetic field with time[8]. This phenomenon is known as longitudinal relaxation, under the rotating coordinate system. Filippi et al[9] reported that the T1p value can sensitively reflect changes in PGs of the intervertebral disc. Also, it has been confirmed that the indicators closely related to PGs such as osmotic pressure, mechanical properties and water content are closely related to T1p values[10]. Changes in the biomechanical properties of the nucleus pulposus are key factors and an important indicator for early degeneration and its structural integrity is dependent primarily on PGs[11]. Reduction of PG content can ultimately lead to a reduction in water content. Therefore, the T1p value is associated with water content. T2 mapping is also based on the changes in water content. Thus, the T1p values T2 mapping values will affect each other. The 2010 study by Blumenkrantz et al[12] showed that T1p values correlated significantly with T2 values ($r = 0.76$, $p < 0.05$). The association between them needs to be further explored. T2 mapping technology is a form of magnetic resonance imaging that can more clearly reflect the structure of cartilage. T2 relaxation, as the decay constant of the T2 signal, is an inherent property of tissue, reflecting the integrated environment of the intervertebral disc, including water, protein, fat, collagen and other solutes. It can detect early changes in composition of cartilage[14]. The water content is a major factor in determining the T2 value. In addition to the fact that T2 changes are associated with degeneration due to ageing, they are related to mapping time, load, position and other factors, all of which can reduce the stability and reliability of T2 measurements[15]. T2 mapping time is longer and has increased demands on patients, and it may be difficult for patients to hold a fixed position because of underlying diseases.

Table IV. Comparison of nucleus pulposus and annulus fibrosus T2 mapping values (ms).

Group category	Nucleus pulposus	Annulus fibrosus
Group A	47.8±11.3	30.3±7.6
Group B	61.2±16.5	45.8±9.2
Group C	83.4±20.7	56.9±11.3
F	12.302	9.642
p	<0.001	<0.001

Increased diffusion of water molecules is associated with higher ADC values, faster signal attenuation and lower DWI signal strength. After changes in composition or structure of tissue, short-term diffusion of water molecules can be affected. By measuring differences in ADC value, lesions can be diagnosed[16] before conventional MRI detects changes in signal or morphology. The value of DWI in diagnosing diseases of the nervous system has been recognized, and progress has also been made for its use in diagnosis of tumors, metastases and articular cartilage degeneration[17]. Perri et al[18] suggest that the ADC values of intervertebral disk hernias are significantly lower and that diffusion weighting may be the pathogenic mechanism of intervertebral disc disease as well as an important means of evaluation for early diagnosis and treatment. The ADC value is mainly affected by the movement and location of water molecules within tissue, including the movement of water molecules within cells, movement of extracellular water molecules, movement of water molecules across cells and blood perfusion of tissues. Among them, blood perfusion and the movement of extracellular water molecules have the greatest impact. For cases where there is no blood perfusion of the nucleus pulposus or inner layer of the annulus fibrosus, the diffusion of extracellular water is the deciding factor in determining the ADC value[19]. The ADC values of the nucleus pulposus reflect the water and PG content. IVDD is primarily caused by degeneration of PG, which will lead to decreased bound water capacity. Thus, the water content within the nucleus pulposus may gradually reduce the changes in PG content, before the reduction of the water content. Changes in water and PG content will result in fluctuations of ADC value. In this regard, there is also a correlation among ADC value, T1p value and T2 value, as well as a difference among them[20].

Conclusions

Here, we demonstrate that the average T1p, T2 mapping and ADC values of the nucleus pulposus and annulus fibrosus in group A were significantly lower than in group B. The highest values were in group C and the difference was statistically significant. With the decreased T2WI signal in the nucleus pulposus, T1p pseudo-color images showed the nucleus pulposus in a uniform blue color gradually and the magnitude of the annulus fibrosus was increased. The magnitude of T2 mapping of the nucleus pulposus core was lower, and the magnitudes were more uniform in the nucleus pulposus region or annulus fibrosus region, where the amplitude of change was lower. The high T1p and T2 mapping values of the intervertebral disc were mainly located in the central region of the nucleus pulposus, while the high ADC values were distributed at the edge of the nucleus pulposus. The difference of high ADC values between the annulus fibrosus and the nucleus pulposus was significant. In summary, there are differences in the diagnostic abilities of T2WI, T1p MRI, T2 mapping and DWI, and they are of great value in improving diagnostic accuracy.

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Conflict of Interests:

The Authors declare that they have no conflict of interests.

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