BMC Musculoskeletal Disorders

RESEARCH

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T2 mapping and q-Dixon for assessment of intervertebral disc degeneration in lower back pain

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Abstract

Background Low back pain(LBP) is very common among the population, and intervertebral disc(IVD) degeneration is considered to be the most common cause of LBP, but the pathophysiological process between IVD degeneration and LBP is not very clear. We conducted this study to clarify the interplay between quantitative magnetic resonance imaging (MRI) parameters, including q-Dixon and T2 mapping, and clinical symptomatology in patients with LBP.

Methods All LBP patients underwent lumbar spine MRI, encompassing q-Dixon and T2 mapping. The severity of pain was classified based on Oswestry Disability Index (ODI) scores. Midsagittal T2 and T2* mapping were used to assess anterior annulus fibrosus (AAF), nucleus pulposus (NP), and posterior annulus fibrosus (PAF), as well as vertebral bone marrow fat fraction (BMFF). ANOVA and Pearson's correlation analyses facilitated the comparative evaluation of MRI parameters with respect to Pfirrmann grades and ODI scores.

Results 95 LBP patients were included (41 males, 54 females), with an average age of 44.39 ± 17.44. The T2 values of AAF and PAF were different and weakly correlated between most Pfirrmann grades ($r = 0.435$, 0.414). T2 and T2* values of NP were different and negatively correlated between all Pfirrmann grades (r=-0.844, -0.704), except for grade IV vs. V, revealing decreasing values for grades I-V. BMFF was different and moderately correlated ($r = 0.646$) between most Pfirrmann grades, except for grade V vs. grade III and IV. The T2 values of AAF, NP, and PAF, the T2* values of the NP, and the BMFF of the vertebrae could distinguish low pain from moderate and severe pain.

Conclusion The T2 and T2* values of AAF, NP, PAF, as well as the BMFF of the vertebrae, can reflect intervertebral disc (IVD) degeneration and may be potentially used to quantitatively detect causes behind LBP.

Keywords T2 mapping, q-Dixon, Intervertebral disc, Pfirrmann grades

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Background

Lower back pain (LBP) is the most common musculoskeletal problem affecting all age groups [1]. It is usually defined as any pain between the lower gluteal folds and last ribs, with or without pain in the lower limbs [2]. Studies have shown that approximately 70-85% of the population encounters LBP at some point [2–4]. Pain and discomfort caused by LPB may interfere with daily activities, work productivity, physical activity, and sleep, which in turn may lead to mood changes and psychological stress [5].

Degenerative disc disease is frequently implicated as a primary etiological factor in LBP [6]. Nevertheless, the pathophysiologic correlation between pain and disc degeneration is not fully understood. The intervertebral disc (IVD) is an important spine structure that connects adjacent vertebrae and supports and stabilizes the spine while keeping it relatively flexible, which is essential for maintaining the stability and normal function of the spine [7]. With aging, degenerative changes in the IVD may lead to structural and functional changes, and these morphological and biochemical alterations hurt the normal biomechanical function of the discs [8]; such degeneration encompasses many changes, including diminished water content, matrix protein degradation, reduced vascularization, and inflammatory processes that collectively precipitate disc elasticity and shock absorption loss [6]. Compromised nutrient supply to disc cells, along with an imbalance in extracellular matrix maintenance, predisposes the IVD to early-life degeneration, potentially manifesting as reduced disc height, annular fissures, and nucleus pulposus (NP) herniation, all of which contribute to LBP [6, 9, 10]. The metabolic activities of adipocytes in lumbar vertebral bone marrow may alter the IVD's local microenvironment, affecting matrix synthesis and degradation [11, 12]. The disc's nutrition mainly depends on endplate osmosis, and changes in bone marrow fat (BMF) content may influence the vascular distribution and function of vertebral endplates [6, 13]. As the bone marrow fat fraction (BMFF) of the vertebral body rises, the vertebral bone mineral density may decrease, reducing the vertebral load-bearing capacity, causing uneven disc pressure, and accelerating disc degeneration over time [14, 15]. Defining the link between BMFF and IVD degeneration helps identify potential degeneration risks in the early stage of disc degeneration, before obvious morphological changes, providing a basis for early intervention and treatment, and enabling better disease prognosis assessment for patients.

Over the last decade, many imaging tools, such as computed tomography (CT), single-photon emission-computed tomography (SPECT), positron emission tomography (PET), plain film radiography, fluoroscopy, and MRI, have been used to investigate the causes of LBP [16, 17]. The method selection is based on many factors, such as the presence of contraindications, patient presentation, availability, relative cost, etc. For example, plain X-ray and nuclear imaging modalities are useful in the initial general assessment [18]. Although proven effective at identifying degenerative diseases like osteoarthritis [18], these methods do not seem accurate enough to detect the causes of LBP. On the other hand, MRI is a powerful tool for studying the etiology and pathophysiology of LBP [19]. Traditional MRI, although a cornerstone in spinal imaging, has notable limitations when it comes to assessing early degenerative changes [20]. The Pfirrmann grade, which is widely used in clinical practice, is based primarily on morphological features and signal intensity alterations [21]. This means that in the early stages of degeneration, when there may be only subtle biochemical changes and minimal morphological disruption, the Pfirrmann grade often fails to detect these alterations [22, 23]. For example, in patients with mild disc dehydration, which is an early sign of degeneration, the traditional MRI may show no significant differences in signal intensity or structure compared to normal discs, leading to an under-diagnosis [24, 25]. Additionally, the subjective interpretation of MRI images by radiologists can introduce variability in the grading, further compromising the accuracy of early detection. Conventional MRI also struggles to quantify the specific biochemical changes occurring within the disc, such as the exact degree of collagen breakdown or proteoglycan loss, which are crucial in understanding the progression of degeneration [26]. However, conventional MRI findings correlate imperfectly with clinical symptoms, underscoring the need for quantitative imaging modalities to detect biochemical alterations preceding overt morphological changes [27–29].

MRI mapping techniques, such as T2 mapping and q-Dixon, offer a more objective assessment of the structural integrity and degenerative status of the IVD and vertebral bodies [30]. In the past, numerous investigations have delved into the relationship between T2 mapping, T2* mapping, BMFF, and disc degeneration as well as LBP [24, 31, 32]. Regarding T2 mapping, multiple studies have established that it can effectively reflect the water content changes within the intervertebral disc [24, 30, 33, 34]. As the disc degenerates, the water content decreases, and this is mirrored by a decline in T2 values [10, 35]. On the other hand, T2* mapping has been proven to be more sensitive to microstructural changes and can be used to assess the biochemical changes, integrity and composition of the collagen matrix [36]. T2 or T2* mapping is feasible for detecting the staging of disc degeneration [37]. Compared with the traditional Pfirrmann classification, MR mapping is less affected by subjective factors, and disc degeneration is more accurately

measured [38], which facilitates the investigation of the interaction mechanism between the vertebral body and the IVD. Furthermore, vertebral BMF content has emerged as a significant indicator negatively associated with bone mineral density and osteoporosis [38, 39].

However, despite these advancements, there remain significant gaps in our understanding. Although the associations between each of these imaging biomarkers (T2 mapping, T2* mapping, BMFF) and disc degeneration or LBP have been explored individually, these studies are insufficient and have not reached highly consistent conclusions. Moreover, there is a lack of comprehensive studies integrating all three to provide a more holistic view of the underlying pathophysiology. This study aimed to demonstrate the potential benefit of BMFF and T2 and T2* mapping in detecting and grading lower back pain patients with disc degeneration. to analyze its relationship with existing clinical scores to assess the diagnostic performance of MR mapping. It also analyzes the relationships between these biomarkers and existing clinical scores to evaluate the diagnostic performance of MRI mapping. The ultimate goal is to provide new targets for the early detection of intervertebral disc degeneration, thus assisting clinical diagnosis and treatment.

Methods

Patients

A total of 128 patients with LBP enrolled in Zigong Fourth People's Hospital between December 2021 and March 2023 were included in this study. Inclusion criteria were: (1) single or recurrent episodes of lower back pain, lumbar leg pain, or sciatica reported in the past 6 months; (2) pain confirmed by an orthopedic surgeon based on patient's history and physical examination; (3) those who underwent lumbar spine MRI. The exclusion criteria were: (1) patients who underwent spinal surgery; (2) patients with acute lumbar trauma; (3) patients with ankylosing spondylitis and spinal infections; (4) patients with scoliosis; (5) patients with lumbar malignant tumors and malignant tumors in other parts of the body; (6) patients with incomplete information on imaging or clinical date; (7) poor image quality.

All patients signed an informed consent before examination, and ethical approval was provided by the hospital's ethics committee of Zigong Fourth People's Hospital.

Image acquisition

All patients were scanned on the same 1.5T MR (Siemens Magnetom Altea), with a 24-channel spine-specific coil (BioMatrix Spine) covering the vertebrae from L1 to S1. The scan was performed with the patient in the supine position; the head was scanned first, and the patient was instructed to breathe calmly and keep the lower back immobile. The scanning protocols were as follows: (1) sagittal turbo spin echo T1-weighted/T2-weighted sequences: repetition time (TR)/echo time (TE) = 500/8.6 ms/3200/93 ms; field of view (FOV) = 300 × 300mm2; slice gap = 0.8 mm; slice thickness = 4 mm; (2) axial turbo spin echo T2-weighted sequences: TR/TE = 1900/94 ms; FOV = 300 × 300 mm^2; slice gap = 0.8 mm; slice thickness = 4 mm; (3) sagittal turbo spin echo T2-mapping sequences: TR = 1200ms, TE1/TE2/TE3/TE4/TE5 = 13.80ms/27.60ms/ 41.40ms/ 55.20ms/69.00 ms; flip angle (FA) = 180°; FOV = 200 × 117 mm^2; slice gap = 0.8 mm; slice thickness = 4 mm; scanning time = 6 min 59 s; (4) 6-echo spin-echo sequence q-Dixon: TR = 10.2ms, TE1/TE2/TE3/TE4/TE5/ TE6 = 1.39ms/2.85ms/4ms/5.77 ms/7.23ms/8.69 ms, FA = 4°, slice thickness = 3 mm, scanning time = 34 s.

Image analysis

All raw data were transferred to the Siemens Syngo post-processing workstation, and the T2 map and q-Dixon map (T2* mapping and BMFF) were obtained by automatic machine calculation, respectively. Two physicians (with 5 and 7 years in MRI diagnosis, respectively) who were blinded to clinical information manually sketched the regions of interest (ROIs) in the median sagittal position. The IVDs were evenly divided into 5 regions to map the ROIs; each of the anterior 1/5 of the IVD represented the anterior annulus fibrosus (AAF), the middle 3/5 represented the nucleus pulposus (NP), and the posterior 1/5 represented the posterior annulus fibrosus (PAF). The T2 and T2* values of AAF, NP, and PAF of each disc from L1-L5, as well as the BMFF values of the vertebral bodies, were measured, after which the average of the measurements made by the two physicians was taken as the final result.

Two diagnostic radiologists (with 7 and 15 years in MRI diagnosis) graded the lumbar IVDs based on the sagittal T2WI without knowing the values of discs T2, T2*, and BMFF. In case of disagreement, a decision was made by discussion. Pfirrmann grading was assessed based on the following criteria [40]: Grade I, homogeneous hyperintense with normal height; Grade II, inhomogeneous hyperintense with or without horizontal bands with normal height; Grade III, inhomogeneous grey, with normal to slightly decreased disc space; Grade IV, inhomogeneous grey to black, with normal to moderately decreased disc space; Grade V, inhomogeneous black with collapsed disc space.

Evaluation of low back pain

The evaluation method of LBP was based on the traditional Chinese version of the ODI 2.1 [41]. Compared to the original ODI, the item referring to "sex life" was removed (as Chinese people are more contained in matters of sex), the total score was changed from 50 to 45,

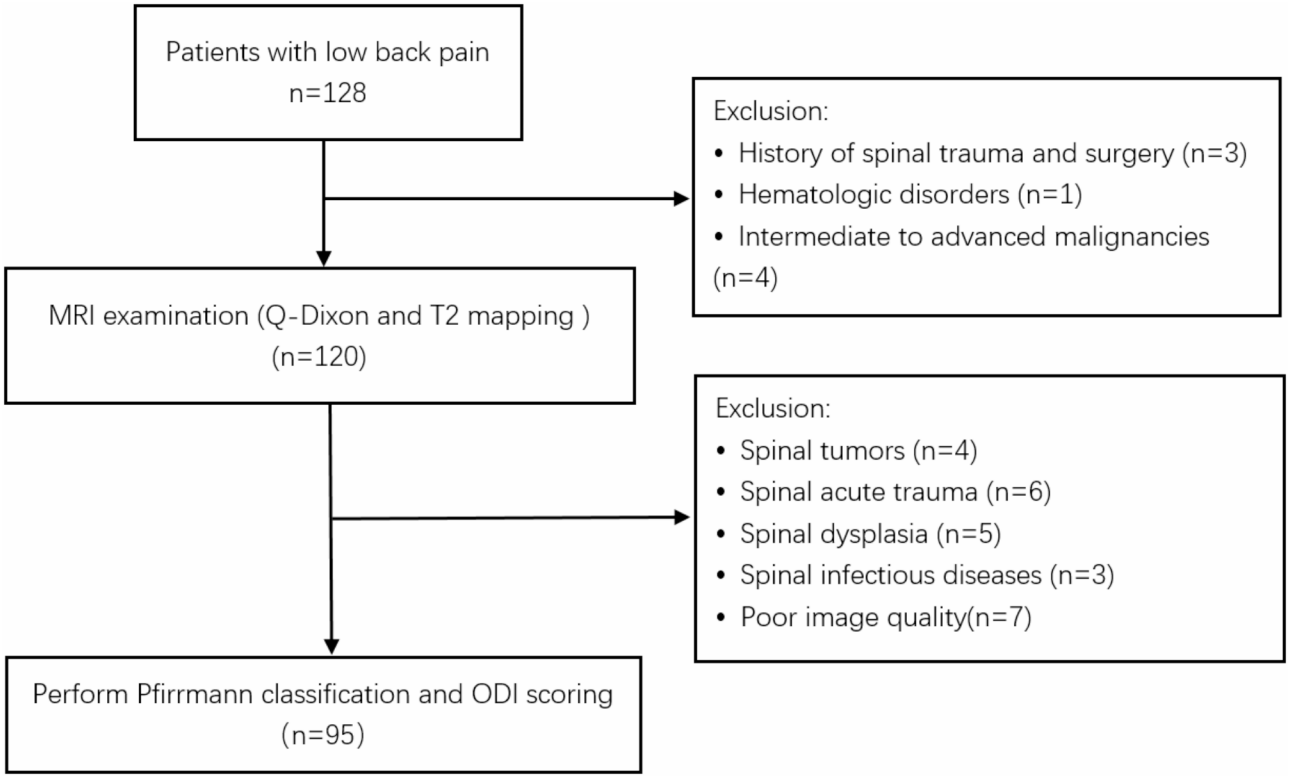

Fig. 1 Study flowchart. MRI = magnetic resonance imaging. ODI = Oswestry Disability Index

and the percentage of the total score (45) was calculated by adding up the corresponding scores of the nine multiple choice answers. The patients were categorized into 3 groups for ODI: ≤20 for mild pain, 21–40 for moderate pain, and > 40 for severe pain.

Statistical analysis

All analyses were performed using SPSS22.0 software. Intraclass correlation coefficient (ICC) was used to evaluate the consistency of the two physicians' measurements of IVD T2, T2*, and BMFF values; if the ICC was ≥ 0.75, the consistency of the measurements between the two observers was considered high; 0.4 ≤ ICC < 0.75 suggested that the consistency was average, and < 0.4 suggested that the consistency was poor. The normality of the data was investigated before subsequent analysis. One-way analysis of variance and post-hoc comparisons were performed for data that were normally distributed; otherwise, Kruskal-Wallis H tests were performed. The ANOVA test was used to compare the differences in T2 and T2* values and BMFF values for IVD of each Pfirrmann classification, as well as different ODI subgroups. Pearson's correlation was used to compare the correlation between the T2 and T2* values of IVD, BMFF values of vertebrae and age, Pfirrmann's grading, and ODI index, and to determine the degree of correlation according to the correlation coefficient: r>0.7 indicated strong correlation, 0.5< r ≤ 0.7 indicated a moderate correlation and r ≤ 0.5 indicated a weak correlation. p<0.05 represented a statistically significant difference.

Table 1 Demographic and clinical data

Characteristic	*N* = 95 people
Age (years)	44.39 ± 17.44
Age of female (years)*n* = 54	47.11 ± 2.29
Age of male (years)*n* = 41	41.54 ± 2.82
Weight (kg)	60.64 ± 10.68
Height (cm)	1.64 ± 0.078
BMI (kg/m^2)	22.56 ± 3.17

Results

General data and ICC

Among a total of 95 finally assessed patients with LBP (41 males and 54 females, with an age range of 16–81 years old and a mean age of 44.39 ± 17.44 years old), 33 were excluded due to lumbar surgery, tumor, infection, trauma and other factors (Fig. 1; Table 1). A total of 475 IVDs and vertebral bodies from 95 subjects were analyzed and measured. For L1 - L5 discs, mean T2 and T2* values of AAF, NP, and PAF showed no peculiarities. Meanwhile, the BMFF values of the vertebral bodies gradually increased from L1 - L4 (Fig. 2). Pfirrmann groups were 46 (9.7%) in grade I, 226 (47.6%) in grade II, 87 (18.3%) in

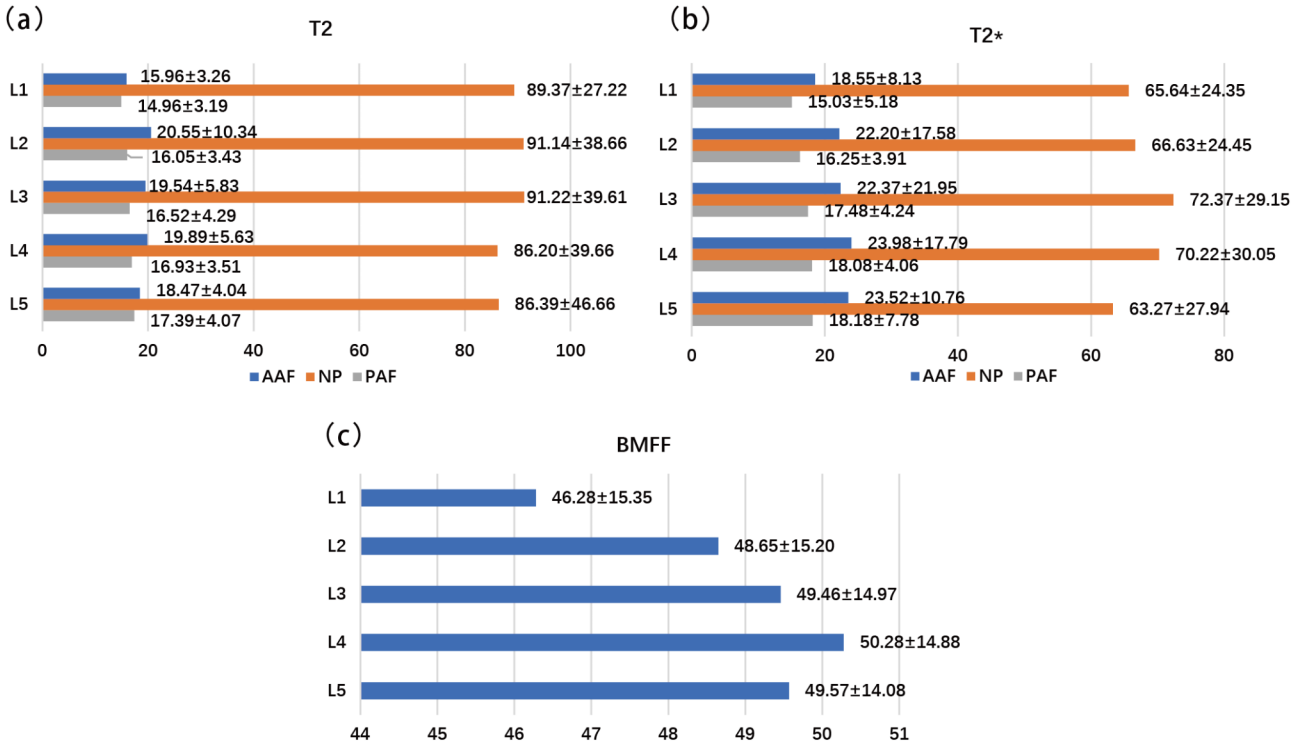

Fig. 2 The mean T2 (a) and T2* (b) values of the AAF, NP, and PAF in the intervertebral discs at L1-L5, as well as the average BMFF (c) of each vertebral body in all subjects. AAF = annulus fibrosus. NP = nucleus pulposus. PAF = posterior annulus fibrosus

Table 2 Differences of BMFF, T2 and T2* mapping in AAF, NP, and PAF of IVD in 5 Pfirrmann groups

	N	BMFF	T2			T2*		
			AAF	NP	PAF	AAF	NP	PAF
I	46	35.75 ± 10.17	17.43 ± 2.61	142.26 ± 35.42	15.36 ± 2.29	25.36 ± 29.52	103.42 ± 25.40	17.89 ± 8.04
II	226	41.92 ± 12.47	16.71 ± 4.16	107.13 ± 27.77	15.00 ± 2.55	21.11 ± 16.00	76.94 ± 23.52	15.88 ± 5.41
III	87	54.98 ± 11.17	20.64 ± 9.20	69.25 ± 16.40	16.94 ± 4.52	21.75 ± 8.19	57.79 ± 15.98	17.64 ± 4.65
IV	102	63.60 ± 8.43	22.33 ± 7.33	47.03 ± 10.20	18.91 ± 4.32	22.61 ± 7.16	44.75 ± 10.83	18.88 ± 3.36
V	14	58.11 ± 13.43	22.70 ± 4.38	45.21 ± 16.62	19.67 ± 3.80	26.60 ± 33.03	27.48 ± 19.34	14.66 ± 4.85
P-values								
I vs. II		0.015	0.046	<0.001	0.216	0.054	<0.001	0.013
I vs. III		<0.001	0.012	<0.001	0.109	0.462	<0.001	0.595
I vs. IV		<0.001	<0.001	<0.001	<0.001	0.096	<0.001	0.005
I vs. V		<0.001	0.001	<0.001	<0.001	0.416	<0.001	0.200
II vs. III		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
II vs. IV		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
II vs. V		<0.001	<0.001	<0.001	<0.001	0.819	<0.001	0.970
III vs. IV		<0.001	0.015	<0.001	<0.001	0.269	<0.001	0.005
III vs. V		0.488	0.037	0.010	0.004	0.184	<0.001	0.090
IV vs. V		0.109	0.388	0.878	0.481	0.056	0.151	0.002

Abbreviations: AAF = anterior annulus fibrosus; NP = nucleus pulposus; PAF = posterior annulus fibrosus; IVD = intervertebral disc; BMFF = bone marrow fat fraction

grade III, 102 (21.5%) in grade IV, and 14 (2.9%) in grade V (Table 2).

The ICC of T2 values of the AAF, NP, and PAF of the IVD measured by the two observers were 0.759, 0.920, and 0.756 respectively. The ICC of the T2* values of AAF, NP, and PAF were 0.783, 0.761, and 0.747 respectively. The ICC of the vertebral BMFF value was 0.966. The measurements made by the two observers showed high agreement across all parameters.

Quantitative MRI data in patients with different pfirrmann grades

Quantitative MRI analysis of the IVDs revealed distinct variations in BMFF, T2, and T2* mapping across the five

Pfirrmann grades, which are indicative of disc degeneration (Fig. 3; Table 2).

BMFF values increased from grade I (35.75 ± 10.17) to grade IV (63.60 ± 8.43) before slightly decreasing in grade V (58.11 ± 13.43). BMFF was statistically significant when comparing Pfirrmann grades I, II, and III (all $P < 0.05$), while there was no difference in Pfirrmann levels IV and V.

For T2 values, differences were detected in AAF, NP, and PAF between most grades (all $P < 0.05$), except for PAF in grade I vs. grade II and grade I vs. grade III. No significant differences in T2 values were found for any region between grades IV and V (Table 2). Regarding T2* values, significant differences (all $P < 0.05$) were found for the following regions: NP regions, for all grades except for grade IV vs. grade V; AAF, for grade II vs. III, grade II and IV; PAF for grade I vs. grade II and IV, grade II vs. grade III and IV, grade III vs. IV, and grade IV vs. V (Fig. 4; Table 2).

Variations in quantitative MRI data concerning ODIC changes

The T2, T2* values, and BMFF values between ODI subgroups with different pain levels are shown in Table 3. Statistically significant differences were observed in T2 values for NP, as the severity of pain escalated from slight to severe (all $P < 0.05$); yet, no difference was found between moderate pain and severe pain either in AAF and PAF, but exist differences between mild pain and both moderate and severe pain. For T2* values, significant differences (all $P < 0.05$) were found for the following regions: AAF and PAF region, for slight pain group vs. severe pain; NP region, for slight pain group vs. moderate pain and severe pain.

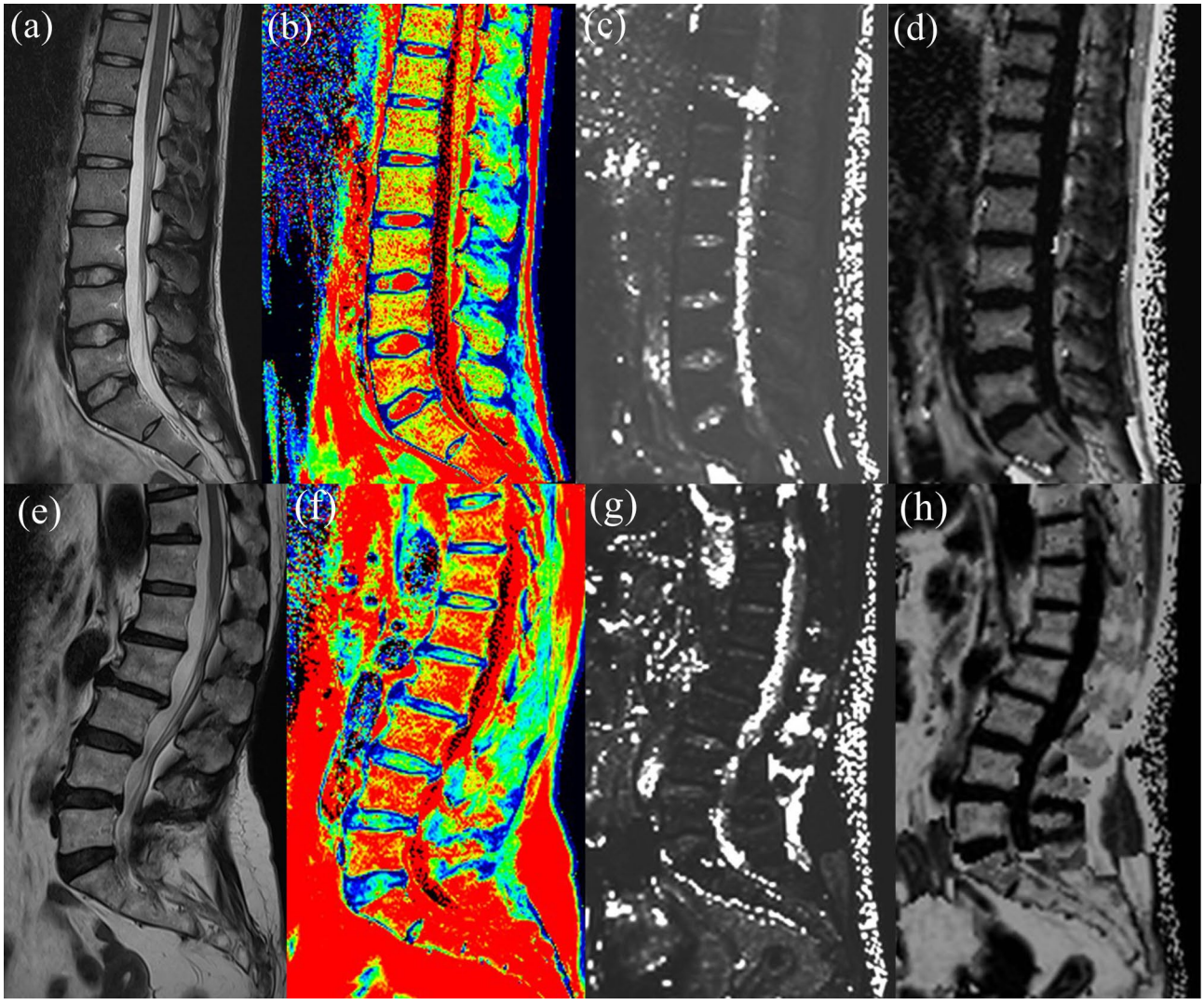

Fig. 3 Representative T2WI (**a**, **e**), T2 maps (**b**, **f**), T2* (**c**, **g**) and BMFF maps (**d**, **h**) of two subjects (Top: 24-year-old male, Pfirrmann classification of grade II. Below: 57-year-old-female, Pfirrmann classification of grade IV-V). BMFF = bone marrow fat fraction

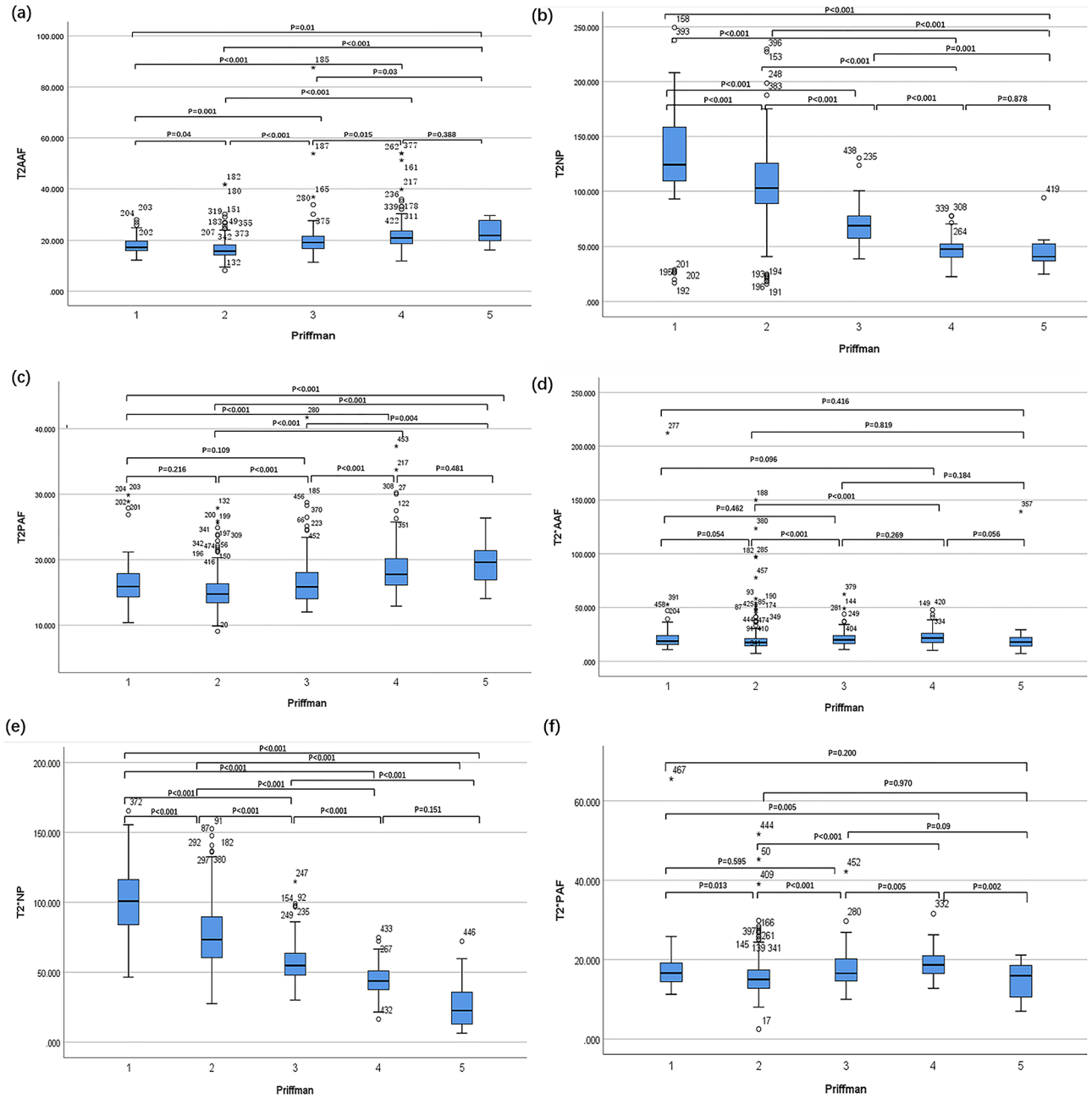

Fig. 4 Boxplots showing differences in T2 (a–c) and T2* (d–f) mapping in AAF, NP, PAF of IVD in different Pfirrmann groups. AAF = anterior annulus fibrosus; NP = nucleus pulposus; PAF = posterior annulus fibrosus; IVD = intervertebral disc

BMFF values demonstrated a significant increase in conjunction with pain severity, with mean values escalating notably from 44.29 ± 14.04 in slight pain to 58.01 ± 12.24 in severe pain ($p < 0.001$ for both 1 vs. 2 and 1 vs. 3) (Table 3).

Correlations between quantitative MRI data, age, Pfirrmann grading, and ODIC classification

The results of the correlation between T2, T2* values of each region of the disc, BMFF values of the vertebrae and age, Pfirrmann grading, and ODI are shown in Table 4. T2, T2* values of AAF and PAF were positively correlated with age, Pfirrmann grading, BMFF and ODI; T2, T2* values of NP were negatively correlated with age, BMFF, Pfirrmann grading and ODI, and the rest were BMFF was strongly positively correlated with age, moderately positively correlated with Pfirrmann grading, and weakly positively correlated with ODI.

Table 3 T2 and T2* values for the AAF, NP, PAF and IVD-total subregions, BMFF of vertebrae in different ODI scores

	1 (*N* = 310)	2 (*N* = 75)	3 (*N* = 90)	*P*-Value 1 vs. 2	*P*-Value 1 vs. 3	*P*-Value 2 vs. 3
T2						
AAF	17.72 ± 5.74	20.76 ± 6.27	21.29 ± 7.99	<0.001	<0.001	0.592
NP	95.67 ± 37.88	82.49 ± 41.74	70.73 ± 32.34	0.007	<0.001	0.046
PAF	15.85 ± 3.63	17.17 ± 4.20	17.47 ± 3.68	0.006	<0.001	0.599
T2*						
AAF	21.32 ± 13.60	21.27 ± 8.49	25.60 ± 25.76	0.984	0.026	0.085
NP	71.96 ± 26.70	62.60 ± 24.97	56.85 ± 28.13	0.007	<0.001	0.169
PAF	16.54 ± 4.58	17.58 ± 5.56	18.09 ± 7.19	0.131	0.015	0.539
BMFF	44.29 ± 14.04	56.67 ± 12.93	58.01 ± 12.24	<0.001	<0.001	0.526

1 classification: slight pain; 2 classification: moderate pain; 3 classification: severe pain. Abbreviations: AAF: anterior annulus fibrosus; NP: nucleus pulposus; PAF: posterior annulus fibrosus; IVD: intervertebral disc; BMFF: bone marrow fat fraction; ODI: Oswestry Disability Index

Table 4 The correlation between T2, T2* value, age, BMFF, Priffmann grading, ODI

Variable	Age	BMFF	Priffmann	ODI
T2				
AAF	***0.483	***0.416	***0.435	***0.336
NP	***-0.783	***-0.618	***-0.844	***-0.350
PAF	***0.348	***0.308	***0.414	***0.267
T2*				
AAF	***0.294	***0.261	***0.178	***0.196
NP	***-0.625	***-0.477	***-0.704	***-0.280
PAF	***0.291	***0.270	***0.253	***0.136
BMFF	***0.743	-	***0.646	***0.415

***$P<0.001$. Abbreviations: BMFF = bone marrow fat fraction; ODI = Oswestry Disability Index; AAF = anterior annulus fibrosus; NP = nucleus pulposus; PAF = posterior annulus fibrosus

Discussion

This study investigated the relationships between quantitative MRI parameters (T2, T2*, and BMFF) and Pfirrmann grading, as well as the ODI in patients with intervertebral disc degeneration. We found that the T2 values of AAF, NP, and PAF, the T2* value of NP, and the BMFF value of the vertebral body correlate well with the anterior and middle stages of disc degeneration and mild clinical symptoms. Yet, the ability to evaluate the severe degenerative changes and clinical symptoms is still limited.

Previous studies have revealed the potential application of T2 mapping and T2* mapping values in assessing disc water content and collagen integrity [20, 22, 34]. T2 mapping is closely related to the distribution and movement status of water molecules in tissues and can be used to indirectly reflect changes in water content in the disc [42–44]. Also, T2* mapping is more sensitive to changes in fibrous tissue integrity [42, 43] and can provide more valuable biochemical information on disc ultrastructure [45]. Although T2 mapping and T2* mapping can accurately reflect the changes in tissue structure, they have very high requirements for magnetic field homogeneity. T2 mapping has a relatively long scanning time, which is prone to interference from motion artifacts. The interpretation of T2* mapping results is relatively complex, and there are many constraining factors. Moreover, both lack large-scale clinical verification. There have also been reports on the application of other quantitative MRI in low back pain. Quantitative changes in lumbar spine tissue, including alterations in water content, proteoglycan levels, and fat accumulation, are closely related to the progression of lumbar spine diseases such as IVD degeneration and LBP. For example, reduced water content and proteoglycan loss in the NP weaken its load-bearing capacity, increasing stress on adjacent tissues and contributing to pain. Similarly, increased BMFF in the vertebral body can impair perfusion and nutrient delivery to the disc, exacerbating degenerative changes and further linking tissue-level alterations to clinical symptoms [27, 38, 39].

Our findings revealed distinct patterns in T2 and T2* values among the AAF, NP, and PAF regions across Pfirrmann grades. The T2 values of AAF and PAF increased with higher grades, a result that likely reflects annulus fibrosus relaxation and increased water infiltration during degeneration. Messner et al. [46]observed similar findings, showing increased T2 values in the PAF region of herniated discs, suggesting that inflammatory responses may also prolong T2 values in these regions. Some studies have reported that disc T2 and T2* values change negatively with Pfirrmann grading [23, 45], nevertheless, these studies analyzed the entire disc, while this study assessed different regions separately. However, other studies [30] reported no significant differences in AF T2 values between normal and degenerated discs, highlighting inconsistencies that warrant further investigation. Although no substantial difference exists between T2 and T2* mapping in terms of the fibrous structural alterations they characterize, T2* mapping benefits from shorter imaging times [36]. However, in this study, the T2* values in the AAF and PAF showed variability and did not correlate significantly with Pfirrmann grading, which might reflect technical challenges such as difficulties in region delineation and sensitivity to magnetic field

inhomogeneity. Previous studies have reported differing trends for T2* values in the AAF and PAF regions, with some observing declines and others noting inconsistent findings [34, 47, 48]. Further research is required to clarify these discrepancies and evaluate the utility of T2* mapping in assessing regional degeneration.

Our study observed a gradual decline in T2 and T2 values in the NP with increasing Pfirrmann grades, which is consistent with previous findings [22, 48]. The gel-like structure of the NP is predominantly composed of water and has a relatively low collagen content. The degenerative process of IVDs has been linked to hydration loss and proteoglycan depletion in the NP [27, 49]. These results likely reflect dehydration and compositional changes associated with disc degeneration. Therefore, it is thus readily comprehensible that the water content in the NP decreases linearly with the degenerative process, thereby leading to a reduction in the T2* value. However, T2 and T2* values showed no significant differences between grades IV and V, suggesting that structural changes may plateau at advanced stages. A previous study [48] has already revealed that as the degree of IVD degeneration progresses, the T2* value of the NP exhibits a downward trend, which is essentially in accordance with our findings. Additionally, in the research by Wu et al. [22], a negative correlation was also identified between the T2* value of the NP and the Pfirrmann grading of the intervertebral disc. Kapoor et al. [36] also considered that the decrease in T2* value can serve as an indicator of early IVD degeneration. Despite their utility, T2 and T2* mapping face challenges, including sensitivity to magnetic field inhomogeneity and motion artifacts.

Our study found that the BMFF derived from q-Dixon imaging, demonstrated a moderate correlation with Pfirrmann grades, with values increasing from grades I to IV but slightly declining at grade V. This trend aligns with studies showing that vertebral marrow fat accumulation impairs nutrient delivery to the disc and contributes to degeneration [9, 39]. However, the slight decline at grade V suggests complex metabolic interactions that may vary with advanced degeneration stages. Previous studies [50, 51] have indicated that increased BMFF is linked to reduced vertebral bone mineral density, further exacerbating disc degeneration by compromising the biomechanical environment. The study by Ji et al. [38] also indicated a significant correlation between intervertebral disc degeneration and bone marrow fat in adjacent vertebral bodies. Importantly, we observed a strong correlation between BMFF and patient age, consistent with its role in age-related spinal changes [52]. Our findings emphasize the potential of BMFF as a biomarker for both age-related and degenerative changes in the spine.

This study also evaluated the relationship between MRI parameters and clinical symptoms. Both T2 and T2* values of the NP decreased with increasing ODI scores, reflecting the structural and biochemical alterations associated with more severe LBP. Additionally, BMFF exhibited a significant increase with escalating ODI scores, highlighting its potential as an indicator of clinical symptom severity. These findings integrate well with prior research [53] linking quantitative MRI biomarkers to lumbar spine conditions. For example, studies have shown that reduced water content and proteoglycan loss in the NP weaken its load-bearing capacity, increasing stress on adjacent tissues and contributing to pain [6, 54, 55]. Similarly, increased BMFF has been associated with impaired nutrient supply to the IVD [20], further linking tissue-level alterations to clinical symptoms.

This study has several limitations. First, the cross-sectional design limits the ability to establish causal relationships between MRI parameters, IVD degeneration, and clinical symptoms. Longitudinal studies are needed to track the progression of degeneration over time. Second, the relatively small sample size and the inclusion of only patients with chronic LBP presenting to the hospital may introduce selection bias, potentially excluding patients with milder symptoms who do not seek medical attention. This may result in an uneven distribution of Pfirrmann grades and limit the generalizability of the findings to the broader population. Third, the lack of a healthy control group prevents direct comparisons with normal IVD parameters, which could provide important context for interpreting the results. Fourth, challenges in accurately applying Pfirrmann grading, particularly for adjacent grades (e.g., I vs. II, III vs. IV), may introduce variability in the assessment of degeneration severity. Lastly, the absence of standardized MRI protocols for quantitative parameters across studies further complicates comparisons with other research. Future studies should address these limitations by including larger, more diverse cohorts, healthy controls, and employing prospective designs to evaluate causal relationships. Additionally, adopting standardized imaging protocols and incorporating longitudinal data will improve the reliability and applicability of quantitative MRI in assessing IVD degeneration.

Conclusion

Our data suggest that T2 and T2* values of the AAF, NP, and PAF and the BMFF values of the vertebral body correlate with IVD degeneration and are particularly sensitive to early IVD changes. Also, there is a difference between the above values in patients with different degrees of lower back pain; therefore, we believe that the T2, T2* values and BMFF values of the vertebral bodies may provide valuable references for quantitatively evaluating the lower back pain.

Abbreviations

LBP	Low back pain
IVD	Intervertebral disc
MRI	Magnetic resonance imaging
ODI	Oswestry disability index
AF	Annulus fibrosus
AAF	Anterior annulus fibrosus
NP	Nucleus pulposus
PAF	Posterior annulus fibrosus
BMFF	Bone marrow fat fraction
CT	Computed tomography
SPECT	Single-photon emission-computed tomography
PET	Positron emission tomography
BMF	Bone marrow fat
ICC	Intraclass correlation coefficient
ADC	Apparent diffusion coefficient

Acknowledgements
Not applicable.

Author contributions
FF, WW, and ML have made substantial contributions to the conception and carried out the studies. FF and WW drafted the manuscript. SL, LL, and MS participated in collecting data. JR and MC performed the statistical analysis and participated in its design. All authors read and approved the final manuscript.

Funding
The research leading to these results received funding from [Science and technology planning project of Zigong Science and technology Bureau] under Grant Agreement No [2023YKY09].

Data availability
Due to ethical restrictions, the data collected and analyzed in this study will not be made publicly available. However, they can be obtained upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
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. The study was approved by the Ethics Committee of Zigong Fourth People's Hospital. (No: EC-2023-085). Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Received: 11 October 2024 / Accepted: 18 February 2025
Published online: 11 March 2025

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