

Association between Spinopelvic Alignment and Lumbar Intervertebral Disc Degeneration Quantified with Magnetic Resonance Imaging T2 Mapping in Patients with Chronic Low Back Pain

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Abstract:

Introduction: Although intervertebral disc degeneration (IVDD) and spinopelvic malalignment are likely key structural features of spinal degeneration and chronic low back pain (CLBP), the correlation analysis has not been fully conducted. This cross-sectional quantitative magnetic resonance imaging (MRI) T2 mapping study aimed to elucidate the association between IVDD and spinopelvic alignment in CLBP patients.

Methods: The subjects included 45 CLBP patients (19 men and 26 women; mean age, 63.8 ± 2.0 years; range, 41-79 years). The T2 values of the anterior annulus fibrosus (AF), the nucleus pulposus (NP), and the posterior AF were evaluated using MRI T2 mapping. We compared the possible correlations of spinopelvic parameters with T2 values of anterior AF, NP, and posterior AF using Pearson's correlation coefficient analysis. T2 values in these regions were classified into upper (L1-L2 and L2-L3), middle (L3-L4), and lower (L4-L5 and L5-S1) disc levels, and we analyzed the correlations with spinopelvic parameters.

Results: There were significant correlations of the anterior AF T2 values with lumbar lordosis ($r = 0.51, p < 0.01$), sacral slope ($r = 0.43, p < 0.01$), sagittal vertical axis ($r = -0.40, p < 0.01$), and pelvic tilt ($r = -0.33, p < 0.01$). In all lumbar levels, T2 values of anterior AF had significantly positive correlation with LL and significantly negative correlation with SVA. In lower disc level, T2 values of anterior AF had significantly positive correlation with SS and significantly negative correlation with PT. T2 values of NP and posterior AF had no significant correlations with spinopelvic parameters in all lumbar disc levels.

Conclusions: In summary, this study indicated that the anterior AF degeneration is associated with hypolordosis of the lumbar spine, anterior translation of the body trunk, and posterior inclination of the pelvis in CLBP. Anterior AF degeneration in all lumbar disc levels was associated with hypolordosis of the lumbar spine and anterior translation of the body trunk. Anterior AF degeneration in lower disc level was associated with posterior inclination of the pelvis.

Keywords:

chronic low back pain, spinopelvic alignment, intervertebral disc degeneration, magnetic resonance imaging T2 mapping

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Introduction

Low back pain (LBP) is a common condition and one of the most serious physiological issues worldwide¹⁻⁵⁾. LBP can be caused by several factors in any part of the complex lower back system, such as the interconnected network of

the spinal muscles, bones, discs, nerves, or tendons in the lumbar spine. Intervertebral disc degeneration (IVDD) is considered to be the principal tissue-based cause of LBP⁶⁾. Many studies have reported on discogenic LBP with respect to pathology, diagnosis, and treatment; however, the underlying mechanism and treatment still remain to be unclear.

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Abnormal sagittal spinal alignment may also cause persistent LBP in patients with lumbar disease^{7,8)}. Moreover, previous studies have reported that sagittal spinal malalignment is associated with the development of a spectrum of spinal disorders⁹⁾.

Magnetic resonance imaging (MRI) is an important modality for diagnosing degenerative intervertebral disc (IVD). Signal variation of the discs on T2-weighted images reflects age and degeneration, allowing for the determination of disc degeneration. In particular, since signal strength on MRI is related to water and proteoglycan content, changes in the MRI signal strength in the nucleus pulposus may be indicative of IVDD^{10,11)}. IVDD has been classified using T2-weighted images with the system described by Pfirrmann et al.¹²⁾; however, because this classification is based on visual evaluation, the quantification of degeneration using this strategy is unclear. Several recent studies have attempted to use MRI T2 mapping and MRI T_{1ρ} mapping to quantify lumbar disc degeneration¹³⁻¹⁷⁾. MRI T2 mapping utilizes the T2 relaxation time to quantify the moisture contents and the collagen sequence breakdown. In our previous work, we used MRI T2 mapping to quantify the extent of IVDD and found a correlation with Pfirrmann classification¹⁸⁾. Furthermore, we quantitatively evaluated IVDD with MRI T2 mapping and reported a correlation between posterior annulus fibrosus (AF) degeneration and chronic low back pain (CLBP)¹⁹⁾.

Although IVDD and spinopelvic malalignment may be key structural features of spinal degeneration and CLBP, a correlation analysis has not been fully conducted. This cross-sectional quantitative MRI study aimed to elucidate the association between IVDD and spinopelvic malalignment in patients with CLBP.

Materials and Methods

Ethical approval was obtained from the Hospital Ethics Committee. All the subjects were provided with written and verbal explanations of the study, and written informed consent has been obtained from them.

Participants

The subjects included patients (41–79 years old) with nonspecific CLBP, characterized by pain, stiffness, and discomfort in the lower back from the 12th rib to the lumbar or lumbosacral area, wherein the source was difficult to identify and whose symptoms had persisted despite conservative treatments, such as medication and therapeutic exercise, for more than 3 months. The exclusion criteria were (i) systemic inflammatory disease; (ii) neurological disorder; (iii) prior spine surgery; (iv) neoplasm, infection, or acute trauma; (v) history of spinal fracture; and (vi) spinal deformities, such as spondylolisthesis with/without obvious instability, indicating sagittal translation ≥ 3 mm, segmental motion $\geq 20^\circ$, or posterior opening $\geq 5^\circ$ on flexion/extension radiographs or scoliosis ($\geq 10^\circ$). Forty-five patients (19 men

and 26 women; mean age, 63.8 ± 2.0 years; range, 41-79 years) satisfied the diagnostic criteria. All subjects completed the LBP visual analogue scale (VAS) assessment (0-100 mm). We calculated body mass index (BMI) as the self-reported body weight (kg) divided by the height squared (m^2).

Radiographic evaluation

We performed full-length spine and pelvic radiography of the subjects in the standing position to determine several parameters, as per a previous report²⁰⁾. The following sagittal spinal radiological parameters were recorded from the sagittal plane of the spine radiographs: lumbar lordosis (LL; the superior endplate of L1 to the superior endplate of S1, Fig. 1a), thoracic kyphosis (TK; the superior endplate of T4 to the inferior endplate of T12, Fig. 1a), and sagittal vertical axis (SVA; the horizontal offset from the posterior-superior corner of S1 to the vertebral midbody of C7, Fig. 1b). The following sagittal pelvic parameters were recorded from the sagittal plane of pelvic radiographs: sacral slope (SS; the angle between the horizontal and upper sacral endplate, Fig. 1c), pelvic tilt (PT; the angle between the vertical and line through the midpoint of the sacral plate to the femoral head axis, Fig. 1d), and pelvic incidence (PI; the angle perpendicular to the upper sacral endplate at its midpoint and the line connecting this point to the femoral head axis, Fig. 1e). Intra- and interobserver reliabilities for measuring spinopelvic parameters were blindly assessed by two investigators (Observer 1, I.O.; Observer 2, H.T.).

MRI T2 mapping

We used the MRI protocol and analyses for MRI T2 mapping that were reported in a previous study^{18,19)}. A T2 map was created using the T2 values in the midsagittal section from the sagittal sections centered on the lumbar midline region with optimized 8 echo multispin echo (TR/first echo TE, last echo TE, 1,000/14.8, 118.6, RBW ± 15.63 kHz, FOV 22 cm, matrix 320×256 , slice thickness/gap 4 mm/4 mm, 5 slices, NEX 2, total scan time 8 min and 34 s) obtained with an Advantage Workstation (version 4.4, Functool; GE Healthcare, Milwaukee, WA, USA). However, the first echo from the multispin system was excluded to minimize the effect of the stimulated echo. The T2 map was calculated in each pixel from the signal intensity (SI) in the respective TE using the following formula: $SI^{1/4} e_{-TE} = T2$

For measurement, the disc was divided into five equal areas, indicating the front fifth of the anterior AF, the middle fifth of the nucleus pulposus (NP), and the last fifth of the posterior AF^{18,19)}, at five functional spinal unit levels (L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1) (Fig. 2a). In the same region, we measured the mean values (Fig. 2b), resulting in a total of 225 levels. The T2 values were measured by a PhD investigator (H.T., with 12 years of experience in spine MR image analysis) using MedCalc (version 10.2.0.0; MedCalc Software, Mariakerke, Belgium).

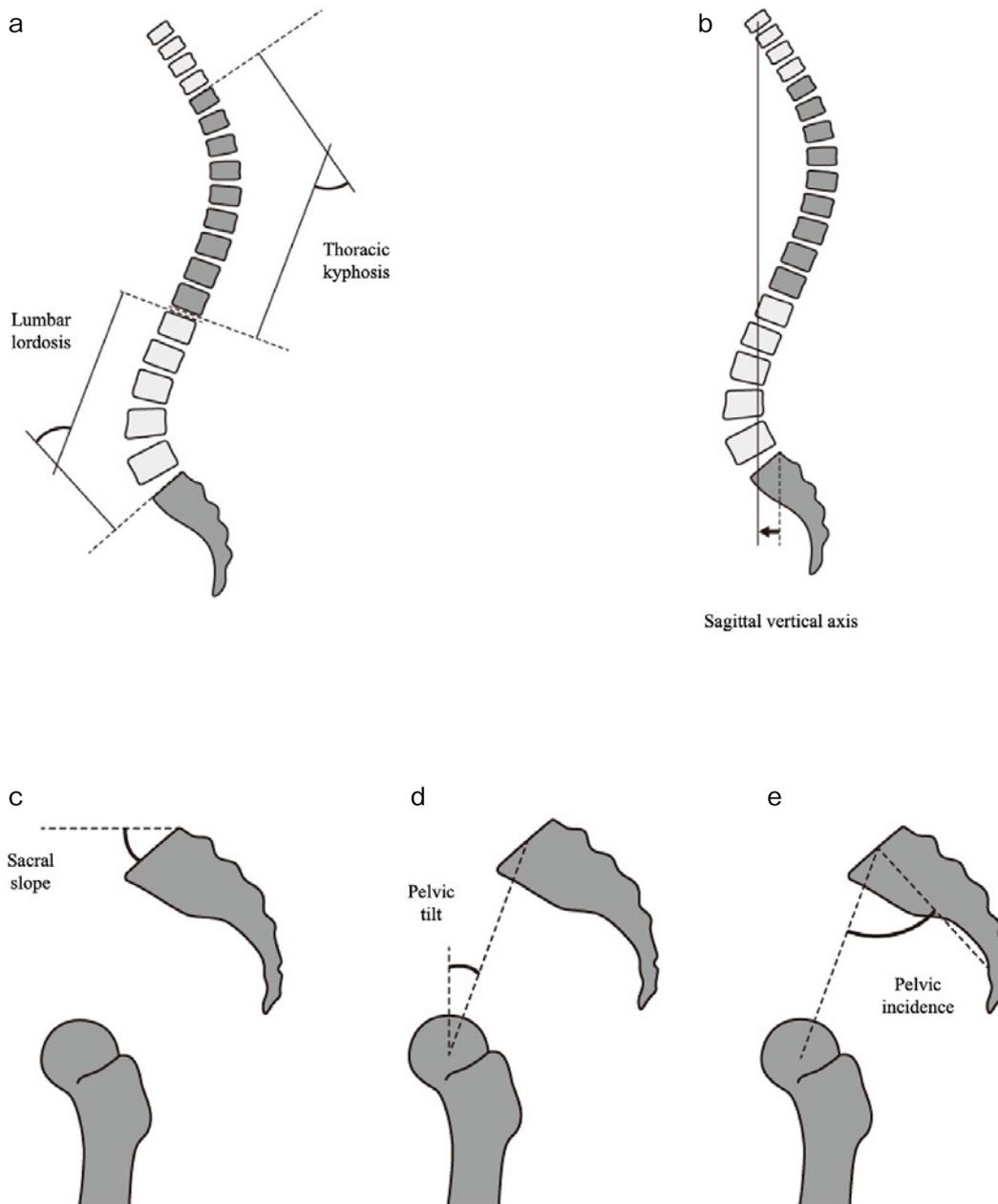


Figure 1. Sagittal spinal radiologic parameters were recorded as follows: lumbar lordosis (LL; the superior endplate of L1 to the superior endplate of S1) (a), thoracic kyphosis (TK; the superior endplate of T4 to the inferior endplate of T12) (a), and sagittal vertical axis (SVA; the horizontal offset from the posterior-superior corner of S1 to the vertebral midbody of C7) (b). Pelvic parameters were recorded as follows: sacral slope (SS; the angle between the horizontal and upper sacral endplate) (c), pelvic tilt (PT; the angle between the vertical and line through the midpoint of the sacral plate to the femoral head axis) (d), and pelvic incidence (PI; the angle perpendicular to the upper sacral endplate at its midpoint and the line connecting this point to the femoral head axis) (e).

Statistical analysis

T2 values were analyzed at each IVD level of the anterior AF, NP, and posterior AF using one-way factorial measures of analysis of variance with Bonferroni *post hoc* testing. Pearson's correlation coefficient was used to identify the correlations of spinopelvic parameters with the total level T2 values (L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1) of anterior AF, NP, and posterior AF. T2 values in these regions were

classified into upper (L1-L2 and L2-L3), middle (L3-L4) and lower (L4-L5 and L5-S1) disc levels, and we analyzed the correlations with spinopelvic parameters. Values of $p < 0.05$ indicated statistical significance. All the numerical data are expressed as the means \pm standard errors of the mean values.

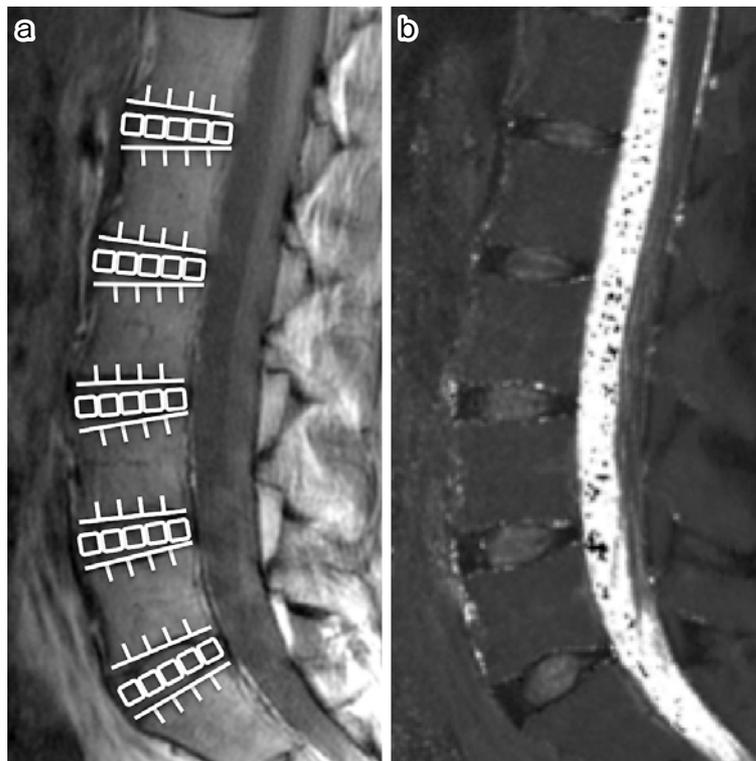


Figure 2. In the second echo image, the disc was divided into five areas, indicating the front of the anterior annulus fibrosus (AF), the middle of the nucleus pulposus (NP), and the last of the posterior AF (a). In the same region, we measured the mean values (b).

Results

The mean BMI was $23.4 \pm 0.5 \text{ kg/m}^2$, and the mean VAS score was $60.1 \pm 2.7 \text{ mm}$. Measurements of the T2 values at each IVD level of the anterior AF, NP, and posterior AF are shown in Fig. 3. The T2 values of the anterior AF, NP, and posterior AF were 67.7 ± 1.9 , 68.0 ± 1.9 , and $61.3 \pm 2.1 \text{ ms}$, respectively, for the L1–L2 level; 68.1 ± 1.8 , 68.2 ± 1.8 , and $60.4 \pm 1.9 \text{ ms}$, respectively, for the L2–L3 level; 61.3 ± 2.2 , 64.7 ± 2.5 , and $57.6 \pm 1.8 \text{ ms}$, respectively, for the L3–L4 level; 58.7 ± 2.0 , 60.0 ± 2.7 , and $52.5 \pm 1.9 \text{ ms}$, respectively, for the L4–L5 level; 59.9 ± 1.9 , 60.3 ± 2.6 , and $55.9 \pm 1.9 \text{ ms}$, respectively, for the L5–S1 level; and 315.7 ± 8.7 , 321.2 ± 9.7 , and $287.7 \pm 5.5 \text{ ms}$, respectively, for the total lumbar spine. The T2 values of the anterior AF at the L3–L4, L4–L5, and L5–S levels were significantly lower than those at the L1–L2 and L2–L3 levels (Fig. 3a). The T2 values of the NP at the L4–L5 and L5–S levels were significantly lower than those at the L1–L2 and L2–3 levels (Fig. 3b). The T2 values of the posterior AF at the L4–L5 level were significantly lower than those at the L1–L2 and L2–L3 levels (Fig. 3c).

The following results were obtained for the spinopelvic parameters: LL, $38.0^\circ \pm 2.6^\circ$; TK, $30.0^\circ \pm 1.9^\circ$; SVA, $36.8 \pm 5.4 \text{ mm}$; SS, $29.0^\circ \pm 1.2^\circ$; PT, $20.4^\circ \pm 1.7^\circ$; and PI, $49.4^\circ \pm 1.7^\circ$. Pearson's correlation coefficient of spinopelvic parameters with T2 values of anterior AF, NP, and posterior AF are shown in Table 1. There was a significantly positive

correlation between the T2 values of anterior AF and LL ($r = 0.51$, $p < 0.01$), as well as between anterior AF and SS ($r = 0.43$, $p < 0.01$), and a significantly negative correlation between the T2 values of anterior AF and SVA ($r = -0.40$, $p < 0.01$) and PT ($r = -0.33$, $p < 0.01$). There were no significant correlations between the T2 values of anterior AF and TK ($r = 0.28$, $p = 0.08$) or between anterior AF and PI ($r = -0.13$, $p = 0.31$). There were no significant correlations of the T2 values of NP with LL ($r = 0.14$, $p = 0.35$), TK ($r = 0.18$, $p = 0.28$), SVA ($r = -0.21$, $p = 0.21$), SS ($r = 0.24$, $p = 0.22$), PT ($r = -0.12$, $p = 0.42$), or PI ($r = -0.09$, $p = 0.39$). There were no significant correlations of the T2 values of posterior AF and LL ($r = 0.13$, $p = 0.36$), TK ($r = 0.14$, $p = 0.34$), SVA ($r = -0.05$, $p = 0.70$), SS ($r = 0.03$, $p = 0.86$), PT ($r = -0.08$, $p = 0.59$), or PI ($r = -0.12$, $p = 0.41$). In all lumbar levels, T2 values of anterior AF had significantly positive correlation with LL and significantly negative correlation with SVA (Table 2). In lower disc level, T2 values of anterior AF had significantly positive correlation with SS and significantly negative correlation with PT (Table 2). T2 values of NP (Table 3) and posterior AF (Table 4) had no significant correlations with spinopelvic parameters in all lumbar disc levels.

For the intra- and interobserver reliabilities, the following results were respectively obtained: LL, 0.86 and 0.93; TK, 0.87 and 0.91; SVA, 0.85 and 0.92; SS, 0.84 and 0.91; PT, 0.83 and 0.87; and PI, 0.82 and 0.89, respectively (Table 5).

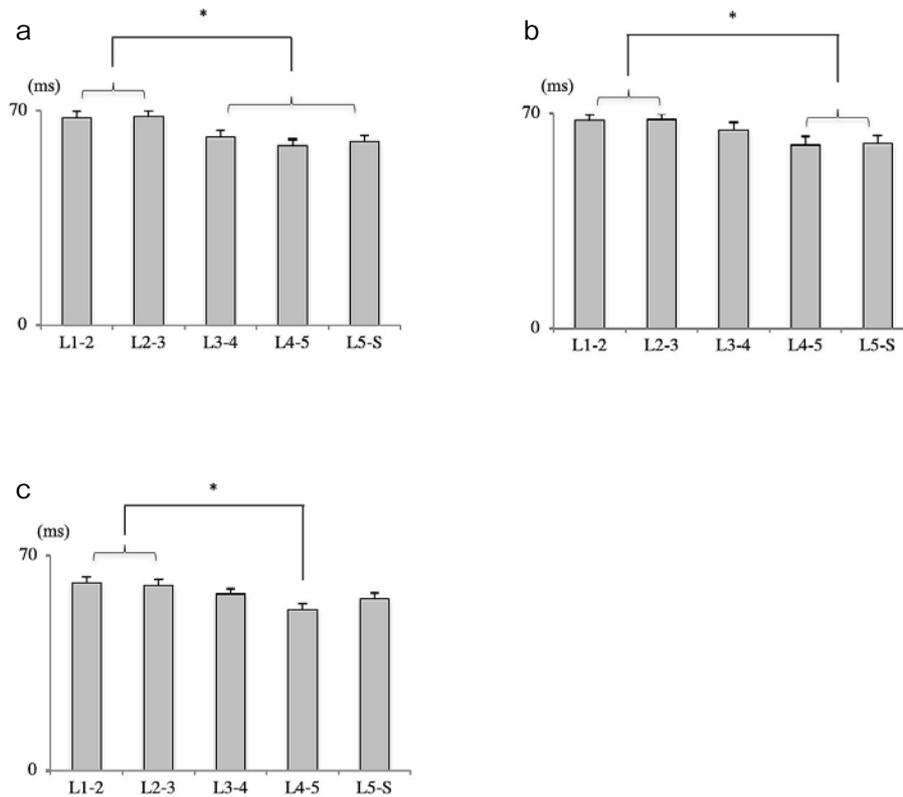


Figure 3. Bar chart showing T2 values at each IVD level of anterior AF (a), NP (b), and posterior AF (c).

(a) T2 values of the anterior AF at the L3–L4, L4–L5, and L5–S levels were significantly lower than that at the L1–L2 and L2–L3 levels.

(b) T2 values of the NP at the L4–L5 and L5–S levels were significantly lower than that at the L1–L2 and L2–L3 levels.

(c) T2 values of the posterior AF at the L4–L5 level were significantly lower than that at the L1–L2 and L2–L3 levels.

Error bars denoted the standard error of the mean.

* $p < 0.01$: one-way factorial measures of analysis of variance with *post hoc* testing performed using the Bonferroni method.

Table 1. Pearson’s Correlation Coefficient of Spinopelvic Parameters with T2 Values of Anterior AF, NP, and Posterior AF.

	Anterior AF		NP		Posterior AF	
	r	p	r	p	r	p
LL (°)	0.51	<0.01	0.14	0.35	0.13	0.36
TK (°)	0.28	0.08	0.18	0.28	0.14	0.34
SVA (mm)	-0.40	<0.01	-0.21	0.24	-0.05	0.70
SS (°)	0.43	<0.01	0.24	0.22	0.03	0.86
PT (°)	-0.33	<0.01	-0.12	0.42	-0.08	0.59
PI (°)	-0.13	0.31	-0.09	0.39	-0.12	0.41

Data are expressed as the mean±standard error of the mean.

AF: annulus fibrosus, NP: nucleus pulposus, LL: lumbar lordosis, TK: thoracic kyphosis

SVA: sagittal vertical axis, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

Table 2. Pearson’s Correlation Coefficient of Spinopelvic Parameters with T2 Values of Anterior AF.

	Upper		Middle		Lower	
	r	p	r	p	r	p
LL (°)	0.31	<0.05	0.41	<0.01	0.69	<0.01
TK (°)	0.29	0.07	0.22	0.20	0.17	0.23
SVA (mm)	-0.41	<0.01	-0.35	<0.01	-0.47	<0.01
SS (°)	0.16	0.22	0.17	0.20	0.51	<0.01
PT (°)	-0.12	0.33	-0.24	0.19	-0.43	<0.01
PI (°)	-0.05	0.68	-0.07	0.59	-0.06	0.64

Data are expressed as the mean±standard error of the mean.

AF: annulus fibrosus, LL: lumbar lordosis, TK: thoracic kyphosis

SVA: sagittal vertical axis, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

Discussion

Sagittal spine curvature has been used as an important significant parameter for the assessment of IVD stresses and

loads in both clinical and cadaveric biomechanical researches^{21,22}. Few MRI studies have examined the association between IVDD and sagittal alignment²³⁻²⁵. Keorochana et al.²³ showed that alternations in sagittal alignment may

Table 3. Pearson’s Correlation Coefficient of Spinopelvic Parameters with T2 Values of NP.

	Upper		Middle		Lower	
	r	p	r	p	r	p
LL (°)	0.11	0.44	0.16	0.27	0.19	0.28
TK (°)	0.22	0.20	0.15	0.29	-0.05	0.71
SVA (mm)	-0.04	0.81	-0.16	0.22	-0.15	0.23
SS (°)	0.07	0.61	0.18	0.25	0.25	0.20
PT (°)	-0.02	0.87	0.06	0.68	-0.13	0.30
PI (°)	-0.06	0.66	-0.11	0.42	-0.04	0.72

Data are expressed as the mean±standard error of the mean.
 NP: nucleus pulposus, LL: lumbar lordosis, TK: thoracic kyphosis
 SVA: sagittal vertical axis, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

Table 4. Pearson’s Correlation Coefficient of Spinopelvic Parameters with T2 Values of Posterior AF.

	Upper		Middle		Lower	
	r	p	r	p	r	p
LL (°)	-0.09	0.57	0.16	0.26	0.06	0.65
TK (°)	0.02	0.92	0.03	0.80	-0.04	0.83
SVA (mm)	-0.02	0.91	-0.11	0.43	0.05	0.69
SS (°)	0.12	0.41	-0.01	0.91	0.02	0.89
PT (°)	0.03	0.81	-0.02	0.87	-0.05	0.73
PI (°)	-0.18	0.27	-0.13	0.31	-0.14	0.30

Data are expressed as the mean±standard error of the mean.
 AF: annulus fibrosus, LL: lumbar lordosis, TK: thoracic kyphosis
 SVA: sagittal vertical axis, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

change the lumbar spine kinematics that may definitively influence load bearing and the incidence of IVDD. Habibi et al.²⁴⁾ reported that IVDD patients seemed to have more straightened lumbosacral profiles. However, rather than quantitative methods, these studies used visual evaluation for estimating IVDD.

In this study, we elucidated the association between IVDD and spinopelvic alignment in CLBP using quantitative MRI and showed a positive correlation of the T2 values of anterior AF with LL and SVA and a negative correlation of the T2 values of anterior AF with SVA and PT. These results indicated that anterior AF degeneration was associated with hypolordosis of the lumbar spine, anterior translation of the body trunk, and posterior inclination of the pelvis. Our results also indicate that anterior AF degeneration in all lumbar disc levels was associated with hypolordosis of the lumbar spine and anterior translation of the body trunk. On the other hand, anterior AF degeneration in lower disc level was associated with posterior inclination of the pelvis. However, whether AF degeneration was the cause or the result of spino-pelvic malalignment was still unknown. Future longitudinal studies are warranted to address this point.

Previously, we evaluated the extent of IVDD and compared it with the T2 values in degenerative spondylolisthesis

Table 5. Intra- and Interobserver Reliabilities Analysis.

	Intraobserver reliability (Observer 1/Observer 2)	Interobserver reliability (Observer 1/Observer 1)
LL (°)	0.86	0.93
TK (°)	0.87	0.91
SVA (mm)	0.85	0.92
SS (°)	0.84	0.91
PT (°)	0.83	0.87
PI (°)	0.82	0.89

LL: lumbar lordosis, TK: thoracic kyphosis, SVA: sagittal vertical axis, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

(DS) and no spondylolisthesis groups to find that the T2 values decreased IVD anterior AF in the DS group²⁶⁾. Therefore, we suggested the possibility of early diagnosis of lumbar DS and expected prediction of adjacent segmental disease after posterior spinal fusion. Similarly, characterization of the relationship between degeneration in the anterior AF and spinopelvic alignment might aid in the accurate noninvasive evaluation of IVDD and subsequent treatment and surgical planning. It would be especially important when making the decision regarding the necessity of fusion surgery. Although little is known about postlaminectomy kyphosis in the lumbar spine²⁷⁾, anterior AF degeneration using MRI T2 mapping could detect a potential spinopelvic malalignment and might be a predictive factor of postoperative spinopelvic malalignment.

This study has certain limitations. First, we employed a cross-sectional design. Longitudinal studies would be necessary for a detailed analysis. Second, we did not perform any evaluation regarding other factors involved in IVDD, such as smoking, diabetes mellitus, hypertension, or physical activity. Third, the number of subjects was small, and there were no control cases in this study. Further investigation with a larger number of subjects and control cases is required.

In summary, this study indicated that the anterior AF degeneration is associated with hypolordosis of the lumbar spine, anterior translation of the body trunk, and posterior inclination of the pelvis in CLBP. Anterior AF degeneration in all lumbar disc levels was associated with hypolordosis of the lumbar spine and anterior translation of the body trunk. Anterior AF degeneration in lower disc level was associated with posterior inclination of the pelvis.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Author Contributions: Izaya Ogon wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

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