Clinical Studies

Association between lumbar segmental mobility and intervertebral disc degeneration quantified by magnetic resonance imaging T2 mapping

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ABSTRACT

Background: The relation between segmental mobility and degree of lumbar degenerative change is still unknown. This cross-sectional study aimed to elucidate the association between intervertebral disc degeneration (IVDD) and segmental mobility in chronic low back pain using magnetic resonance imaging (MRI) T2 mapping.

Methods: Subjects comprised 60 patients (29 men, 31 women; mean age, 61.8 ± 1.9 years; range, 41–79 years). T2 values of the anterior annulus fibrosus (AF), the nucleus pulposus (NP) and the posterior AF were evaluated with MRI T2 mapping. Facet joint degeneration was divided into 4 grades using MRI. We analyzed the correlation between segmental mobility and T2 values of anterior AF, NP and posterior AF using multiple linear regression analysis adjusted for age and facet joint degeneration.

Results: The standardized partial regression coefficient of the anterior AF, NP and posterior AF T2 values were 0.125 (p=0.72), 0.499 (p<0.01) and –0.026 (p=0.11), respectively, for the L1-2 level; 0.102 (p=0.27), 0.395 (p<0.01) and –0.094 (p=0.20), respectively, for the L2-3 level; 0.108 (p=0.38), 0.415 (p<0.01) and –0.050 (p=0.51), respectively, for the L3-4 level; 0.124 (p=0.09), 0.396 (p<0.01) and 0.025 (p=0.73), respectively, for the L4-5 level; and 0.011 (p=0.89), 0.443 (p<0.01) and 0.030 (p=0.72), respectively, for the L5-S level. There was a significantly positive correlation between segmental mobility and the T2 values of NP at L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1. No significant correlations arose between segmental mobility and the T2 values of the anterior AF and the posterior AF at L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1.

Conclusion: Characterization of the relationship between NP degeneration and lumbar segmental mobility may enhance our ability to evaluate the changes seen in kinematics of functional spinal unit.

Background

Intervertebral disc degeneration (IVDD) is a principal tissue-based cause of low back pain (LBP) [1] and loss of normal motion segment function [2]. Spinal dysfunction instability following degenerative changes in the lumbar spine may manifest as chronic low back pain (CLBP) [3]. In clinical practice, radiographical assessment of bending motions of the lumbar spine is important as it may help in identifying the motion segment function in patients suffering from CLBP and help guide the course of clinical treatment.

Magnetic resonance imaging (MRI) is an important modality for diagnosing of IVDD. Signal variation of the discs on T2-weighted images reflects age and degeneration, allowing for the determination of disc degeneration. In particular, because the signal strength of the MRI is related to water and proteoglycan content, changes in the MRI signal strength in the nucleus pulposus (NP) may be indicative of IVDD [4].

Previous studies have demonstrated that the IVDD severity may also influence segmental mobility [5–9]. In these studies, a visual evaluation grading system was developed to classify IVDD. Recent studies have reported using MRI T2 mapping [10–14] and MRI T_{1p} mapping [15] to attempt to quantify lumbar disc degeneration. MRI T2 mapping utilizes the T2 relaxation time for quantifying the moisture contents and the collagen sequence breakdown. We previously used MRI T2 mapping to quantify the extent of IVDD and found a correlation with Pfirrmann classifications [11].

In the present cross-sectional study, we aimed to elucidate the association between IVDD and segmental mobility in CLBP using MRI T2 mapping.

Methods

Ethical approval was obtained from the Hospital Board of Ethics. All the subjects received written and verbal explanations of the study, and all provided informed consent before participation in the study.

Participants

Subjects comprised patients (41–79 years old) with non-specific CLBP without neurologic symptoms of the lower leg, characterized by pain, stiffness, and discomfort in the lower back from the twelfth rib to the lumbar or lumbosacral area, wherein the source was difficult to identify. Furthermore, the symptoms of all participants had persisted for more than three months despite conservative treatments such as medication and therapeutic exercise. The exclusion criteria were as follows: (i) systemic inflammatory disease; (ii) neurological disorder; (iii) prior spine surgery; (iv) neoplasm, infection, or acute trauma; (v) history of spinal fracture, and (vi) spondylolisthesis with or without obvious instability, indicating sagittal translation ≥ 3 mm, segmental mobility ≥ 20 °, or posterior opening ≥ 5 ° on flexion/extension radiographs, (vii) scoliosis ($\geq 10°$), or (viii) ligamentous ossification. A total of 60 patients (29 men and 31 women; mean age, 61.8 ± 1.9 years; range, 41–79 years) satisfied the diagnostic inclusion criteria. All subjects completed the LBP visual analogue scale (VAS) scores (0–100 mm). We calculated the body mass index (BMI) using the self-reported body weight (kg) divided by the height squared (m^2).

Radiographic evaluation

We performed the dynamic flexion-extension radiographs of the subjects in the standing position. Segmental mobility was defined as the angle difference in degrees, between flexion and extension at five intervertebral disc (IVD) levels (L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1), measured by drawing lines along the superior borders of the vertebrae in each motion segment and extending them until they join and calculating the differences of these angles.

Intra- and interobserver reliabilities for measuring of each segmental mobility were blindly assessed by two investigators (Observer 1; I.O. and Observer 2; H.T.).

Assessment of facet joint osteoarthritis on MRI

In order to evaluate the facet joint osteoarthritis, the Signa HDx 1.5T MRI system (GE Healthcare, Milwaukee, WI, USA) with a spine coil was
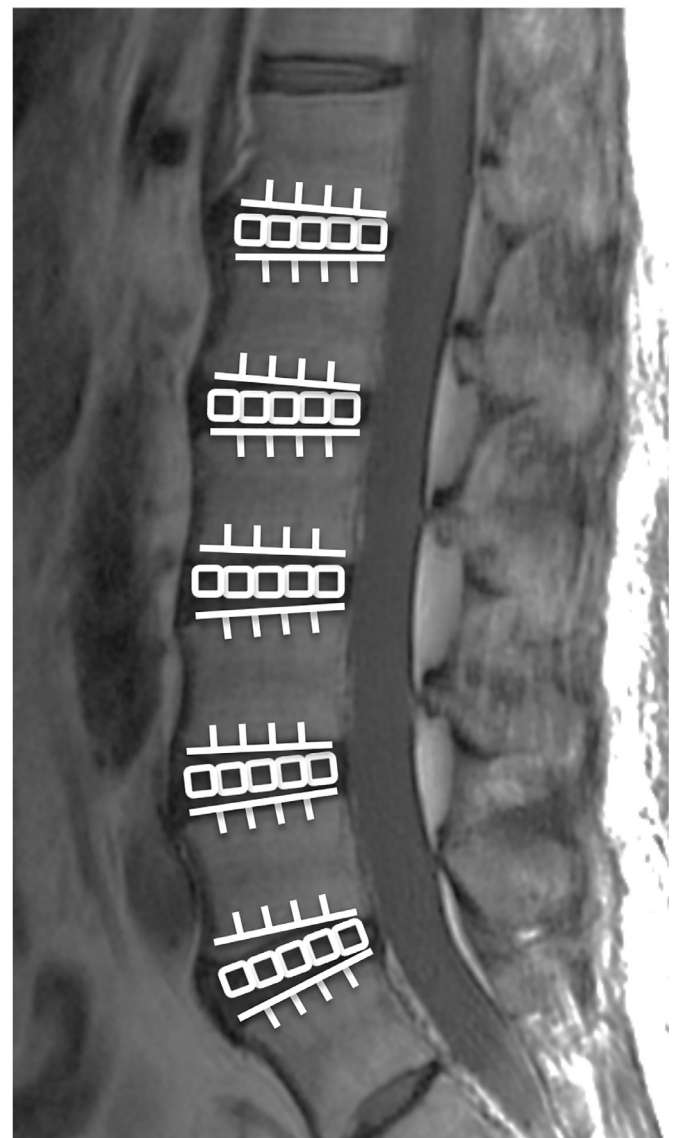

Fig. 2. In the second echo image, the disc was divided into five equal areas, designating the front fifth of the anterior annulus fibrosus (AF), the middle fifth of the nucleus pulposus (NP), and the last fifth of the posterior AF, at five intervertebral disc (IVD) levels (L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1).

used to obtain the T1-weighted axial MR images at five lumbar levels (L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1). Facet joint degeneration was divided into 4 grades, in which grade 1=corresponded normal; grade 2=joint space narrowing or a mild osteophyte; grade 3=a sclerosis or moderate osteophyte; grade 4=a marked osteophyte [16]. When there was a difference in the severity of facet joint degeneration between right and left at the same motion segment, the worst grade was recorded.

MRI T2 mapping

We used the MRI protocol and analyses for MRI T2 mapping, as per a previous study [11–14]. Sagittal images for T2 mapping were acquired and T2 maps were created on a pixel-by-pixel basis in the supine position (Fig. 1). We used 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,
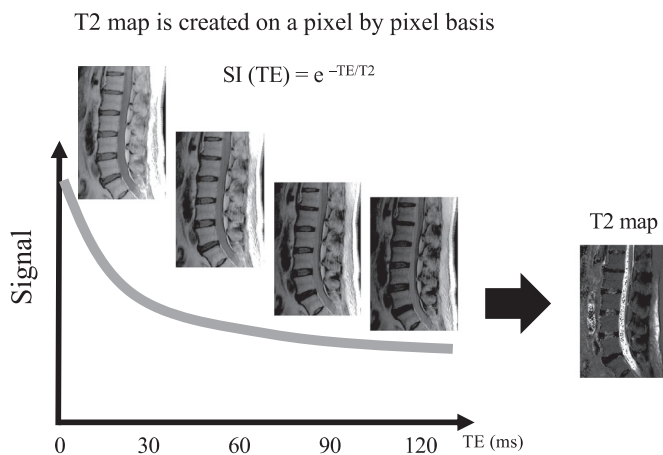

Fig. 1. An illustration of the T2 fitting and quantification procedure. Sagittal images for T2 mapping were acquired and T2 maps were created on a pixel-by-pixel basis.

T2 map is created on a pixel by pixel basis

$SI (TE) = e^{-TE/T2}$

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 (TE) = e $^{-TE/T2}$.

For measurement, the disc was divided into five equal areas, designating the front fifth of the anterior AF, the middle fifth of the nucleus pulposus (NP), and the last fifth of the posterior AF [11–14], at five IVD levels (L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1) (Fig. 2). In the same region, we measured the mean values, resulting in a total of 300 levels. The T2 values were measured by a PhD (H.T., with 12 years of experience in spine MR image analysis) with MedCalc (version 10.2.0.0; MedCalc Software, Mariakerke, Belgium).

Statistical analysis

We analyzed the correlation between segmental mobility and T2 values of anterior AF, NP and posterior AF using multiple linear regression analysis adjusted for age and facet joint degeneration. Values of $p < 0.05$ indicated statistical significance. All statistical analyses were performed using SPSS version 22.0 (IBM Japan, Tokyo, Japan). All numerical data are expressed as means ± standard error of the mean values.

Results

The mean BMI was 23.7 ± 0.6 kg/m^2, and the mean VAS score was 57.7 ± 2.7 mm.

The mean segmental mobility was 8.2° ± 0.4° at L1–L2, 9.1° ± 0.5° at L2–L3, 9.4° ± 0.6° at L3–L4, 10.1° ± 0.9° at L4–L5, and .9° ± 0.7° at L5–S1
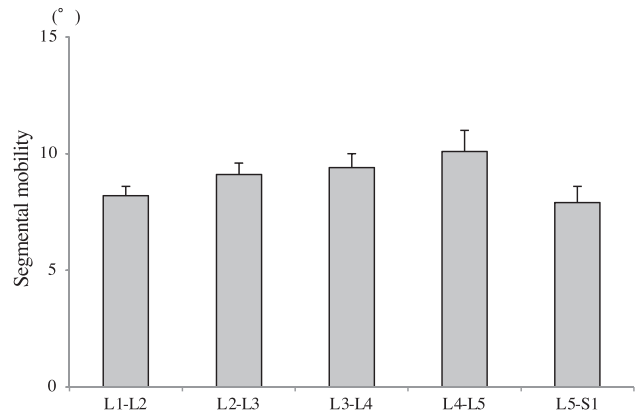
Fig. 3. Bar chart showing the segmental mobility at each IVD level. Error bars denoted the standard error of the mean (SEM).

(Fig. 3). At L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 levels, the following results were, respectively, obtained for facet join degeneration grade: I, 48, 45, 33, 26 and 26; II, 11, 10, 20, 17 and 17; III, 1, 5, 6, 12 and 12; IV, 0, 0 1, 5 and 6 (Table 1).

Measurements of the T2 values at each IVD level of anterior AF (Fig. 4a), NP (Fig. 4b) and posterior AF (Fig. 4c) are shown. The T2 values of the anterior AF, NP, and posterior AF were 66.5 ± 2.9 ms, 70.5 ± 2.3 ms, and 60.5 ± 1.7 ms, respectively, for the L1–L2 level; 67.9
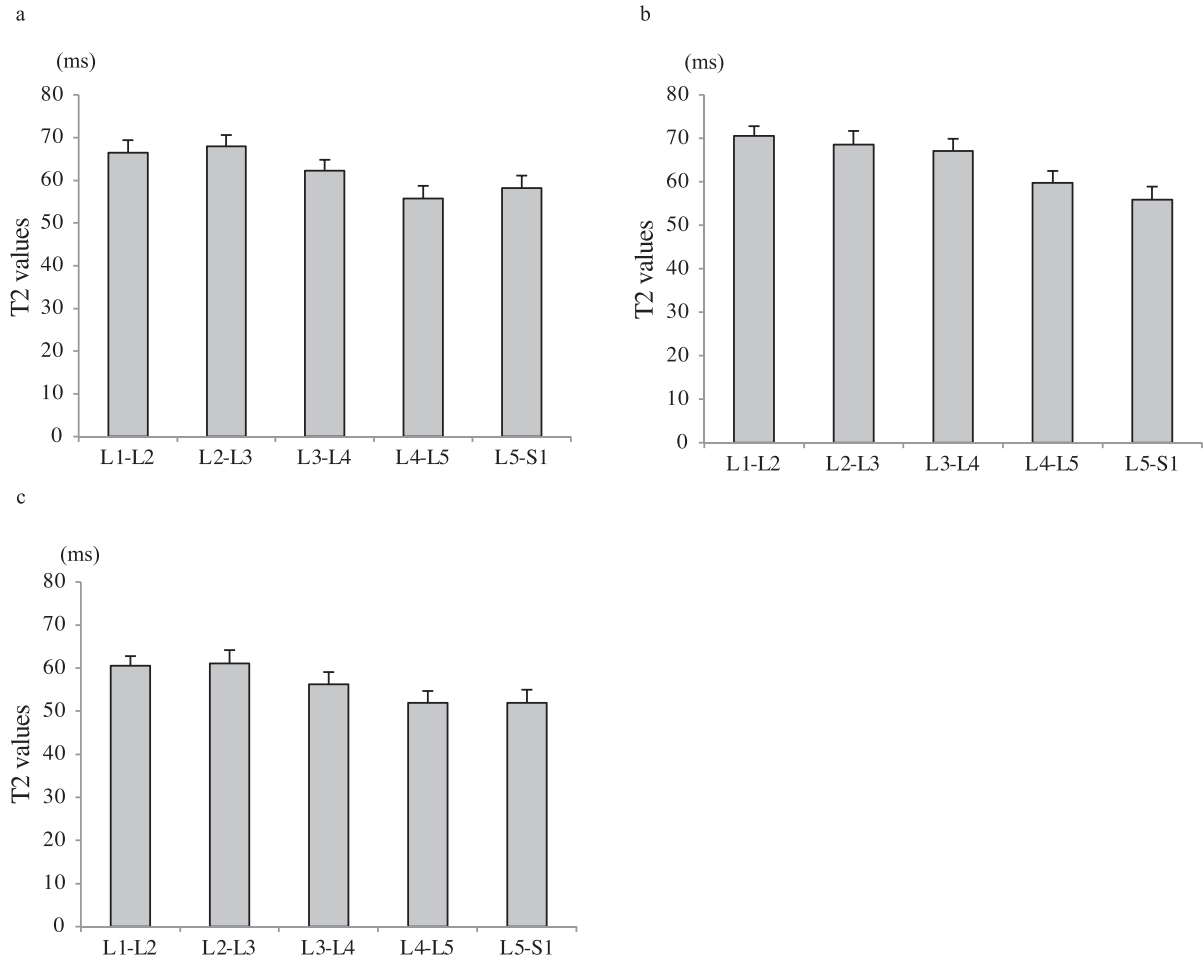
a

b

c

Fig. 4. Bar chart showing the T2 values at each IVD level of anterior AF (a), NP (b) and posterior AF (c). Error bars denoted the SEM.

Table 1

The numbers of each facet degeneration grade at L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 levels.

		Lumbar level				
		L1/2	L2/3	L3/4	L4/5	L5/S
Facet degeneration grade	I	48	45	33	26	26
	II	11	10	20	17	16
	III	1	5	6	12	12
	IV	0	0	1	5	6

Table 3

Intra- and interobserver reliabilities analysis.

	Intraobserver reliability (Observer 1/Observer 1)	Interobserver reliability (Observer 1/Observer 2)
L1–L2	0.93	0.91
L2–L3	0.92	0.89
L3–L4	0.92	0.88
L4–L5	0.89	0.87
L5–S1	0.88	0.86

± 2.7 ms, 68.6 ± 3.1 ms, and 61.1 ± 2.7 ms, respectively, for the L2–L3 level; 62.2 ± 2.6 ms, 67.1 ± 2.8 ms, and 56.3 ± 1.9 ms, respectively, for the L3–L4 level; 55.7 ± 3.0 ms, 59.7 ± 2.8 ms, and 51.9 ± 1.7 ms, respectively, for the L4–L5 level; and 58.2 ± 2.9 ms, 55.9 ± 3.0 ms, and 52.0 ± 2.0 ms, respectively, for the L5–S1 level.

Table 2 showed the correlation between segmental mobility and T2 values of anterior AF, NP and posterior AF using multiple linear regression analysis adjusted for age and facet joint degeneration. The standardized partial regression coefficient of the anterior AF, NP and posterior AF T2 values were 0.125 ($p=0.72$), 0.499 ($p<0.01$) and –0.026 ($p=0.11$), respectively, for the L1-2 level; 0.102 ($p=0.27$), 0.395 ($p<0.01$) and –0.094 ($p=0.20$), respectively, for the L2-3 level; 0.108 ($p=0.38$), 0.415 ($p<0.01$) and –0.050 ($p=0.51$), respectively, for the L3-4 level; 0.124 ($p=0.09$), 0.396 ($p<0.01$) and 0.025 ($p=0.73$), respectively, for the L4-5 level; and 0.011 ($p=0.89$), 0.443 ($p<0.01$) and 0.030 ($p=0.72$), respectively, for the L5-S level. There was a significantly positive correlation between segmental mobility and the T2 values of NP at L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1. No significant correlations arose between segmental mobility and the T2 values of the anterior AF and the posterior AF at L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1.

The following results were obtained for the intra- and interobserver reliabilities: L1–L2, 0.93 and 0.91; L2–L3, 0.92 and 0.89; L3–L4, 0.92 and 0.88; L4–L5, 0.89 and 0.87; and L5–S1, 0.88 and 0.86, respectively (Table 3).

Conclusions

Knowledge of lumbar segmental mobility is critical for understanding lumbar spine disease, and may help to predict how treatments that affect lumbar segmental mobility will affect adjacent motion segments. However, the relation between motion segment function and degree of degenerative changes in the lumbar spine in CLBP patients is still controversial [5,6,17,18]. Some studies have reported that biomechanical instability tends to increase during the early stages of degeneration, and

stabilization of motion segments occurs spontaneously in the advanced stages [5,6]. Others have reported a monotonous increase in biomechanical stability with increasing IVDD in flexion/extension and lateral bending motions, but not in axial rotation [17,18]. These contradictory findings may partly be attributed in part of their use of a visual evaluation and not quantitative methods for estimating IVDD.

In this study, we elucidated the association of IVDD and segmental mobility in CLBP using MRI T2 mapping and showed a positive correlation between the T2 values of NP with segmental mobility. These results suggest that NP degeneration is associated with segmental mobility. Characterization of the relationship between degeneration in the NP and lumbar segmental mobility may enhance our ability to evaluate the changes seen in kinematics at each functional spinal unit. Future studies comparing long-term clinical and MRI T2 mapping findings as they pertain to IVDD, loss of normal motion segment function, and CLBP will be extremely useful.

The incidence of symptomatic, postfusion adjacent segment disease (ASD) ranged from 5.2% to 18.5% [19]. Although several studies have reported that the resulting hypermobility from surgical fusion may be the cause of ASD, it still remains controversial whether it is because of the fusion or simply a result of natural progression of spinal disease [20]. A better understanding of how IVDD affects the kinematics of the adjacent segments may lead to clearer decisions regarding its treatment and postsurgical complications. Future MRI T2 mapping studies analyzing prediction of adjacent segmental disease after spinal fusion will be extremely useful.

This study has certain limitations. First, we employed a cross-sectional design, but longitudinal studies are necessary for detailed analyses. Second, we have not considered the other possible causes of segmental mobility such as degenerative changes of facet joints.

In summary, the present study indicates that the NP degeneration is associated with segmental mobility in CLBP. Characterization of the relationship between NP degeneration and lumbar segmental mobility

Table 2

The correlation between segmental mobility and T2 values of anterior AF, NP and posterior AF using multiple linear regression analysis adjusted for age and facet joint degeneration.

Dependent variable	Independent variable	Regression coefficient	Standard Error	Standardized partial regression coefficient	p
Segmental mobility (L1-2)	Anterior AF	0.020	0.013	0.125	0.72
	NP	0.102	0.024	0.499	<0.01
	Posterior AF	−0.005	0.014	−0.026	0.11
Segmental mobility (L2-3)	Anterior AF	0.021	0.019	0.102	0.27
	NP	1.088	0.325	0.395	<0.01
	Posterior AF	−0.016	0.012	−0.094	0.20
Segmental mobility (L3-4)	Anterior AF	0.021	0.024	0.108	0.38
	NP	0.093	0.032	0.415	<0.01
	Posterior AF	−0.007	0.011	−0.050	0.51
Segmental mobility (L4-5)	Anterior AF	0.020	0.012	0.124	0.09
	NP	1.090	0.327	0.396	<0.01
	Posterior AF	0.003	0.009	0.025	0.73
Segmental mobility (L5-S)	Anterior AF	0.003	0.019	0.011	0.89
	NP	0.088	0.022	0.443	<0.01
	Posterior AF	0.004	0.011	0.030	0.72

AF: annulus fibrosus, NP: nucleus pulposus.

may enhance our ability to evaluate the changes seen in kinematics at each functional spinal unit.

Declaration of Competing Interest

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Sources of funding

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2020.100044.

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