Kinetic magnetic resonance imaging analysis of thoracolumbar segmental mobility in patients without significant spondylosis

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Abstract
To observe thoracolumbar segmental mobility using kinetic magnetic resonance imaging (kMRI) in patients with minimal thoracolumbar spondylosis and establish normal values for translational and angular segmental motion as well as the relative contribution of each segment to total thoracolumbar segmental motion in order to obtain a more complete understanding of this segmental motion in healthy and pathological conditions.

Mid-sagittal images obtained by weight-bearing, multi-position kMRI in patients with symptomatic low back pain or radiculopathy were reviewed. The translational motion and angular variation of each segment from T10–L2 were calculated using MRAnalyzer Automated software. Only patients with a Pfirrmann grade of I or II, indicating minimal disc disease, for all thoracolumbar discs from T10–T11 to L1–L2 were included for further analysis.

The mean translational motion measurements for each level of the lumbar spine were 1.15 mm at T10–T11, 1.20 mm at T11–T12, 1.23 mm at T12–L1, and 1.34 mm at L1–L2 (P < .05 for L1–L2 vs T10–T11). The mean angular motion measurements at each level were 3.26° at T10–T11, 3.92° at T11–T12, 4.95° at T12–L1, and 6.85° at L1–L2. The L1–L2 segment had significantly more angular motion than all other levels (P < .05). The mean percentage contribution of each level to the total angular mobility of the thoracolumbar spine was highest at L1–L2 (36.1%) and least at T10–T11 (17.1%; P < .01).

Segmental motion was greatest in the proximal lumbar levels, and angular motion showed a gradually increasing trend from T10 to L2.

Abbreviations: kMRI = kinetic magnetic resonance imaging, MR = magnetic resonance, MRI = magnetic resonance imaging, SD = standard deviation.

Keywords: degeneration, low back pain, segmental motion, thoracolumbar spine

1. Introduction
The thoracolumbar junction includes a transition zone between the relatively immobile kyphosis of the thorax and the flexible lordosis of the lumbar region. This zone is more prone to pathologic fractures, which can cause severe complications such as neurologic deficits and kyphotic deformities. Thus, the properties of this zone are of great clinical interest in the management of thoracolumbar spinal segmental motion and the application of operative measures in the presence or absence of neurologic deficits.[1–3] Previous studies have reported on adjacent segment degeneration and segment instability due to thoracolumbar instrumentation[4–6] and dynamic stabilization has been applied in patients with degenerative thoracolumbar spine disease.[7] However, relatively few studies have investigated the mechanical behavior and segmental motion of the thoracolumbar spine, and limited data have been collected from human cadaveric specimens,[8–10] radiographic analysis,[11] and in vivo measurements.[12,13] Moreover, previous studies were conducted either on specimens or in patients confined to bed, and thus, the data were unable to accurately reflect the dynamic changes in spinal movement under loading. In contrast, our study followed cases who could maintain the condition of a normal standing posture and support a certain load. What’s more, these previous studies did not consider the effect of age-related disc degeneration at one level on the segmental motion at adjacent or subadjacent levels, which might play an important role in the flexibility of the human thoracolumbar spine. A comprehensive understanding of the natural mechanical behaviors of the thoracolumbar motion segments in the absence of significant degenerative disc disease would permit a more complete understanding of the pathologic changes to segmental motion and the symptoms likely associated with these changes.

We have previously used kinetic magnetic resonance imaging (kMRI) to measure the cervical and lumbar segmental motion of the spine in neutral, flexion, and extension positions.[14,15] In the present study, we aimed to apply kMRI to determine the
kinematics of each spinal motion unit in the thoracolumbar spine with only minimal disc degenerative changes. The collected imaging results were used to establish normal values for translational and angular segmental motion and the relative contribution of each segment to total thoracolumbar segmental motion.

2. Materials and methods

2.1. Patient population

Of the 368 thoracolumbar magnetic resonance imaging (MRI) records reviewed, a total of 100 patients (45 men and 55 women) with grade I or II degeneration at all thoracolumbar levels were included. The mean age of patients was 36.4 years (range, 17–48 years). The exclusion criteria included: a previous history of spinal surgery, vertebral fractures, tumor, or scoliotic deformity and ankylosing spondylitis. The thoracolumbar functional units (T10–T11, T11–T12, T12–L1, and L1–L2) were analyzed. The institutional review board of our hospital approved this study, and informed consent was obtained from all participants.

2.2. Kinetic MRI

kMRI was performed with a 0.6 T MRI scanner (Upright Multi-Position, Fonar Corp., New York, NY). The scanner was equipped with 2 vertically oriented opposing magnet doughnuts placed 18 in apart, allowing the scan to be performed on a patient in upright axially loaded flexion, extension, and neutral positions. Images were obtained using a quad channel planar coil. Assessments were made on T1-weighted sagittal spin echo images (repetition time 671 ms, echo time 17 ms, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, and NEX 2) and T2-weighted fast spin echo images (repetition time 3000 ms, echo time 140 ms, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, and NEX 2) for each patient.

On the T2-weighted kMR images, mid-sagittal views were marked for digitalization by spine surgeons from T10 to L2 in flexion (30°), neutral position, and extension (20°). Each vertebral body was marked at 4 points (the anterior-inferior, anterior-superior, posterior-inferior, and posterior-superior corners; Fig. 1C). The translational and angular motions for each segment were calculated automatically using MR Analyzer Version 3 software (Truemetric Corp., Bellflower, CA).

2.3. Thoracolumbar disc degeneration

All patients were referred for kMRI due to complaints of low back pain with or without leg pain. Three blinded spine surgeons (A–C) graded the degree of disc degeneration on T2-weighted neutral sagittal images according to the grading system proposed by Pfirrmann et al[16] (Table 1). Grade I (Fig. 1A) and grade II discs (Fig. 1B) were considered mildly degenerative. Grade III and grade IV discs were considered moderately degenerative. Grade V discs were considered severely degenerative. Intra- and interobserver agreements were assessed among the 3 observers using kappa statistics. The reliability of the MRI grading was estimated using agreement percentages and kappa statistics within the 3 observers (intraobserver reliability) and between the 3 observers (interobserver reliability). Agreement was categorized as follows: kappa value 0–0.2 indicated slight agreement; 0.21–0.4, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.8, substantial agreement; and ≥0.81, excellent agreement. Only patients with grade I or II discs at all thoracolumbar vertebral segments (Fig. 1C) were included for analysis.

2.4. Segmental translational and angular motion

The segmental translational and angular motions at various thoracolumbar intervertebral disc levels (T10–T11, T11–T12, T12–L1, and L1–L2) were calculated during flexion and extension. Segmental translation was defined as the difference in displacement between 2 vertebrae from flexion to extension.

![Figure 1. Thoracolumbar discs were graded according to the Pfirrmann grading system. (A) Grade I: The structure of the disc is homogeneous, with a bright or hyperintense white signal intensity and normal disc height. (B) Grade II: The structure of the disc is inhomogeneous, with a hyperintense white signal. The distinction between the nucleus and anulus is clear, but the disc height is normal, with or without horizontal gray bands. (C) Only patients demonstrating grade I or II discs at all thoracolumbar vertebral segments (Fig. 1C) were included for analysis.](image-url)
Segmental angulation was defined as the difference in intervertebral angles between 2 vertebrae from flexion to extension (Fig. 2C and D). The contribution of each thoracolumbar level to the total angular mobility was measured to describe the role of each spine unit in the changes of sagittal alignment. It was defined as follows: (angular motion of each segment in degrees)/(sum of the individual sagittal angular variations in degrees) \times 100.

2.5. Statistical analysis

Data are presented as mean ± standard deviation (SD). Statistical analyses were performed using SPSS software (version 15, SPSS, Chicago, IL). The Mann–Whitney test was used for comparisons among the 4 thoracolumbar levels. The level of significance (P value) was set at less than .05.

3. Results

3.1. Intra- and interobserver agreement

The estimated kappa values for the intra- and interobserver agreement on kMRI grading are provided in Table 2. Intraobserver agreement was found to be excellent with kappa values ranging from 0.932 to 0.964. Interobserver agreement among the 3 readers also was excellent with kappa values ranging from 0.865 to 0.912.

| Observer | Kappa value | Agreement (%) | Observer | Kappa value | Agreement (%) |
|----------|-------------|---------------|----------|-------------|---------------|
| A        | 0.932       | 93.8          | A–B      | 0.912       | 90.8          |
| B        | 0.947       | 95.5          | A–C      | 0.865       | 86.3          |
| C        | 0.964       | 96.2          | B–C      | 0.873       | 86.5          |

A, B, and C represent 3 blinded observers who graded the thoracolumbar discs.
The mean values of translational motion for each thoracolumbar level are listed in Table 3. The average translation values were 1.15 ± 0.77 mm at T10–T11, 1.20 ± 0.71 mm at T11–T12, 1.23 ± 0.81 mm at T12–L1, and 1.34 ± 0.79 mm at L1–L2 (Fig. 3A). Translational motion was noted to be similar in the proximal thoracolumbar segments (T10–T11 to T12–L1), whereas L1–L2 motion units exhibited significantly greater translational motion than the T10–T11 level (P < .05).

### 3.3. Angular motion

The mean values of angular variation for each thoracolumbar level are listed in Table 3. The mean angulation values were 3.26 ± 2.28° at T10–T11, 3.92 ± 2.90° at T11–T12, 4.95 ± 3.12° at T12–L1, and 6.85 ± 3.49° at L1–L2. Angular motion tended to increase along the thoracolumbar spine from the proximal to distal level (Fig. 3B). The L1–L2 segments had the highest angular mobility compared with that at the other 3 thorax levels (P < .01). In addition, the T12–L1 level had significantly greater angular variation compared with the T10–T11 (P < .01) and T11–T12 (P < .05) motion units.

With respect to the contribution of each segment to the total angular mobility, the L1–L2 segmental unit contributed the most to the total angular mobility of the thoracolumbar spine (Fig. 4), with a contribution significantly greater than T10–T11 (P < .01), T11–T12 (P < .01), and T12–L1 (P < .05; Table 3). The T12–L1 motion unit contributed a significantly greater percentage of the total angular mobility compared with the T10–T11 (P < .01) and T11–T12 (P < .05) units.

### 3.4. Gender analysis

The study population included 45 men and 35 women. Comparisons between the genders were performed based on the translational and angular motion values for individual segments. No significant differences were observed between male and female patients at any thoracolumbar motion segment (Table 4).

### 4. Discussion

The results of our study demonstrated that the thoracolumbar segmental mobility had kinematic changes in translational and angular motion while altering positions from flexion to extension. Our results indicated that the translational motion of the proximal lumbar spine (L1–L2) was significantly greater than the upper thoracic spine (T10–T11). Moreover, angular motion showed a gradually increasing trend from T10 to L2 and L1–L2 segment had significantly more angular motion than all other levels.
The thoracolumbar spine is the most frequently injured spinal region, because it contains the junction between the relatively rigid thoracic and more flexible lumbar spine. A thorough understanding of thoracolumbar segmental motion is valuable to understand thoracolumbar spine disease and may help predict how treatments that affect thoracolumbar segmental mobility will affect adjacent motion segments. In the current study, we evaluated several hundred thoracolumbar spine magnetic resonance (MR) images and selected patients without significant spondylosis at any function level to determine the relative contributions of each motion segment to translational and angular motion in the thoracolumbar spine. Translational motion was greatest in the L1-L2 level, whereas angular motion tended to increase along the thoracolumbar spine from the proximal to distal level.

For translational motion, the effect of the ribs gradually decreases and, at the T1–T12 level, should be minimal as floating ribs and translational motion gradually increase in the proximal to distal direction. For angular variation, the L1-L2 level contributed the most to the total angular mobility of the thoracolumbar junction. The angular motion tended to increase from T10–T11 to L1-L2 level, from the relatively immobile thoracic to the flexible lumbar spine. The dramatic changes in the facet orientation from the frontal plane to sagittal plane might be a possible reason and mainly affect angular variation.

Previous studies evaluated segmental motion in the thoracolumbar spine using a variety of methods including biomechanical analysis in human cadaveric specimens, flexion-extension radiographs, and invasive wires. Oxlund and Lin [10] conducted a study to determine the three-dimensional mechanical behavior of T1 T11–T12 and T12–L1 segments. Similar to the findings in our current study, the T12–L1 segmental motion was slightly greater than that at T11–T12. Gercsek et al [12] described a direct invasive approach to study dynamic angular three-dimensional measurements of multisegmental thoracolumbar motion in vivo. First, k-wires were inserted into the T11–L2 spinous process of 21 healthy subjects, and real-time motion data were recorded during standardized exercises. This is in contrast to our study of patients without significant spondylosis, in which the highest angular motion occurred at the T12–L1 level, followed by the L1-L2 level and finally the T11–T12 level.

However, in the analyses discussed above, the thoracolumbar motion units were considered in isolation, without considering the effect of age-related disc degeneration at one level on the segmental motion at adjacent or subadjacent levels. Actually, however, intervertebral disc degeneration has been shown to play an important role in the flexibility of the human thoracolumbar spine. Adams et al [18] reported that thoracolumbar disc degeneration transfers compressive loading from the anterior vertebral body to the neural arch in upright postures, predisposing the patient to anterior vertebral fractures. Relatively normal values for thoracolumbar segmental motion will be beneficial for defining the effects of disc degeneration on segmental motion.

The assessment of thoracolumbar motion is also of benefit for evaluating the effects of spinal fusion on adjacent, unfused segments and to help determine if adjacent segment disease is secondary to surgical fusion or part of the natural history of thoracolumbar spondylosis. When motion at a highly flexible segment is eliminated through fixation, the motion and accompanying forces are thought to be transferred to the adjacent level, and this may lead to an accelerated degeneration, especially proximal to the fused segment. [11] Thus, it is important to define the thoracolumbar segmental motion and elucidate the changes that occur with disc degeneration from the normal state to an unstable phase and even to a kyphosis and ankylosed stage.

Although we evaluated normal values for thoracolumbar segmental motion, there were some limitations to our present study. Patients were referred for an MRI based on symptoms of low back pain or radiculopathy and thus were not completely normal. In addition, patients with grade II discs were included in the study, and thus, their measurements were only relatively normal. Lastly, other factors such as degenerative changes in the facet joint, the ligamentum flavum, and the paraspinal muscles also might play important roles in determining abnormal segmental mobility individually or in combination with disc degeneration. [14, 19] Despite these limitations, the present study defined normal thoracolumbar segmental mobility in a large population with a safe and practical imaging technique.

### Table 4

| Spinal level | Translational motion (mm) | Angular variation (degrees) |
|--------------|---------------------------|----------------------------|
|              | Male          | Female         | P value | Male           | Female         | P value |
| T10–T11      | 1.06 ± 0.72  | 1.10 ± 0.61   | .550    | 3.29 ± 2.41  | 3.90 ± 2.77   | .248    |
| T11–T12      | 1.19 ± 0.73  | 1.13 ± 0.59   | .779    | 3.65 ± 2.95  | 4.32 ± 3.33   | .332    |
| T12–L1       | 1.14 ± 0.62  | 1.08 ± 0.59   | .662    | 5.54 ± 2.86  | 4.52 ± 3.54   | .058    |
| L1–L2        | 1.19 ± 0.70  | 1.20 ± 0.77   | .986    | 6.03 ± 2.88  | 7.54 ± 4.53   | .150    |
| Total        | 4.59 ± 1.54  | 4.51 ± 1.24   | .800    | 18.51 ± 6.12 | 20.19 ± 8.66 | .350    |

Men (n = 55, mean age: 35.8 years), women (n = 45, mean age: 37.3 years).
Values are presented as mean ± SD.
The P value was set as < .05, and no significant difference was observed.

In the current study, we used kMRI to measure thoracolumbar segmental mobility in patients without significant spondylosis to define the relative contribution of each thoracolumbar segment to the total segmental motion. Information on the kinematics of this spinal region shows a gradually increasing trend from T10 to L2, this result is valuable for understanding and treating spine disorders such as degenerative disc disease and for evaluating phenomena such as adjacent segment disease when a fusion surgery to the thoracolumbar is required. In addition, the results of this study will allow for future studies in which changes from these values are observed in patients with different degenerative pathologies of the thoracolumbar spine.

5. Conclusion

In the current study, we used kMRI to measure thoracolumbar segmental mobility in patients without significant spondylosis to define the relative contribution of each thoracolumbar segment to the total segmental motion. Information on the kinematics of this spinal region shows a gradually increasing trend from T10 to L2, this result is valuable for understanding and treating spine disorders such as degenerative disc disease and for evaluating phenomena such as adjacent segment disease when a fusion surgery to the thoracolumbar is required. In addition, the results of this study will allow for future studies in which changes from these values are observed in patients with different degenerative pathologies of the thoracolumbar spine.
Author contributions

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