Rotational hypermobility of disc wedging using kinematic CT: preliminary study to investigate the instability of discs in degenerated scoliosis in the lumbar spine

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Received: 10 July 2009 / Revised: 14 January 2010 / Accepted: 16 January 2010 / Published online: 6 February 2010
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Abstract The number of patients showing lumbar degenerative scoliosis, including disc wedging, has increased, and examination of the mechanism of spinal nerve compression due to lateral and rotational mobility of the lumbar spine is necessary. Thirty-two patients with L4–L5 disc wedging but without antero- or retropseudolisthesis and ten age-matched controls were examined. The angle of disc wedging and change in the angle between left and right bending were evaluated by anterior–posterior X-ray images of patients while they were in a standing position. The degree of disc degeneration and existence of vacuum phenomena were evaluated at the L4–L5 discs. Rotational mobility between maximal right and left rotation was examined by computed tomography (CT). Rotational mobility was measured using the spinal transverse processes of L4 and L5. The relationship between these factors was statistically evaluated using multivariate analysis and Spearman’s correlation test. There was a significant increase in the average rotational mobility of the L4–L5 disc-wedging group. In the L4–L5 disc-wedging group, the increased angle of disc wedging and change in the angle between left and right bending correlated with increased rotational mobility. The degree of disc degeneration did not affect rotational mobility. However, existence of vacuum phenomena increased the rotational mobility of the L4–L5 disc-wedging group. This is the first study to

evaluate the rotational hypermobility of L4–L5 disc wedging in patients without antero- or retropseudolisthesis using kinematic CT. Increases in the wedging angle and abnormal instability of lateral bending correlated with increased rotational mobility. For surgical planning of degenerative L4–L5 disc wedging, it is important to consider rotational hypermobility using kinematic CT or X-ray imaging findings of lateral bending.

Keywords Rotational mobility · Lumbar · Intervertebral disc · Computed tomography

Introduction

The Japan Spine Research Society conducted a nationwide survey of 16,157 patients at 196 institutions who had undergone spinal surgery for several lumbar diseases, including lumbar-degenerated scoliosis [12]. The report indicated that half of all the patients had undergone fusion surgery. However, indications for spinal fusion remain controversial. In patients with antero- or retropseudolisthesis, radiographic evaluation of instability using lateral radiographs of the spine in flexion and extension is widely used as an indication for fusion, but this method has been reported to have poor sensitivity and specificity [8]. Especially in cases of lumbar-degenerated scoliosis, the patients have disc wedging involved with rotational instability, though the patients do not show antero- or retropseudolisthesis on X-ray evaluation. In these patients, estimation of the instability of the spine seems to be important; however, kinetic evaluation has not been fully conducted.

When degenerative changes in the discs or facet joints of the lumbar spine induce lumbar scoliotic curvature, the

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condition is called degenerative lumbar scoliosis [2]. Toyone et al. [23] reported that computed tomography (CT) showed both lateral slipping and rotation in adult lumbar scoliosis patients and the significance of estimating axial rotation using plain CT. However, this report was not a kinematic study and did not evaluate the dynamic instability of the axial plane. To study axial rotation of the lumbar spine, a variety of methods have been used to determine instability by measuring segmental motion, including flexion–extension and bilateral radiographs, surgical implantation of wires, magnetic resonance imaging (MRI), and CT [4, 6, 13, 18]. However, the rotational instability of lumbar disc wedging associated with lumbar scoliosis has not been reported.

We hypothesized that rotational instability of L4–L5 disc wedging exists in patients without antero- or retrospondylolisthesis. The ultimate goal of this study was to clarify the rotational vertebral instability of degenerative scoliosis. However, it is difficult to detect overall rotational instability in patients when it involves many discs.

Pritchett and Bortel [21] suggested that degenerative lumbar scoliosis may start with instability at the L3–L4 and L4–L5 discs. Furthermore, L4–L5 disc wedging is frequently found in clinical cases. Thus, our first step was to clarify the rotational vertebral mobility of L4–L5 disc wedging in patients without antero- or retrospondylolisthesis. We did this using kinematic CT to compare the angle of disc wedging, change in the angle between left and right bending as determined by anterior–posterior views of X-rays, the degree of disc degeneration, and the existence of vacuum phenomena in the disc.

Patients and methods

This study was approved by the ethics committee of our institution, and informed consent was obtained from each of the participants.

Patients

This study was a cross-sectional study. Low back pain, continuing for at least 2 weeks, was found in 212 patients in our hospital. Of the 212 patients, 32 patients were diagnosed with lumbar spondylosis on X-ray image evaluation and with L4–L5 disc wedging (L4–L5 disc-wedging group: 15 men, 17 women, average age 67 years). Ten age-matched controls who had low back pain but did not show abnormality on X-ray image evaluation (control group: 5 men, 5 women, average age 69 years) were also examined. The control group did not show L4–L5 disc wedging, and neither group displayed antero- or retrospondylolisthesis. MRI confirmed that patients with other spinal diseases, such as spinal canal stenosis, disc herniation, infection, trauma, or tumors were excluded from the study (Table 1).

Evaluation of intervertebral disc

The degree of disc degeneration in each patient was graded from 1 to 5 (severe degeneration) based on Pfirrmann's grading system using 1.5 T MRI [20]. Existence of vacuum phenomena in the L4–L5 intervertebral disc was also evaluated using three-dimensional (3D)-CT reconstruction [9]. A blinded evaluation was performed by three observers. If at least two of the three observers were in agreement, their classification was used to define the degree of intervertebral disc degeneration (Table 1).

X-ray image evaluation

For all 42 patients, the angle of disc wedging, length of lateral slipping, and change in angle between left and right bending (both 20°) were evaluated using an anterior–posterior view from X-ray films taken when patients were in a standing position. We hypothesized that an increase in the change in angle between left and right bending correlated with an increase in rotational mobility on kinematic CT.

Table 1 Demographic characteristics

	L4/5 disc-wedging group	Control group	Statistical analysis
Number of patients	32	10	
Sex (male:female)	15:17	5:5	
Age range (mean $\pm$ SEM) (years)	58–77 (67 $\pm$ 6)	62–77 (69 $\pm$ 5)	NS
Symptom duration, mean (range) (years)	3 (1–8)	2.5 (1–5)	NS
MRI findings (L4/5)			
Pfirrmann's grade	Grade 2: 0	Grade 2: 3	NS
	Grade 3: 12	Grade 3: 3	NS
	Grade 4: 20	Grade 4: 4	NS
	Grade 5: 0	Grade 5: 0	NS
CT findings (L4/5)			
Vacuum phenomenon	25	3	$P < 0.05$

Measurements of 20° were made by a physician using a goniometer. If the patient felt low back and leg pain while bending left and right, their body was supported in the 20° position on both sides (Fig. 1).

CT evaluation for rotational mobility

Rotational mobility was determined by examining maximal right and left rotation on CT (Toshiba, Tokyo, Japan) (Fig. 2). To ensure uniform body rotation, the patients flexed their right knee at 90° and had both of their arms in contact with the horizontal plane in a prone position (left rotation). Subsequently, the patients flexed their left knee at 90° and had both of their arms in contact with the horizontal plane in a supine position (right rotation).

Serial CT slices of 0.3 mm were taken from the L4 to L5 levels. Rotational mobility was measured from the spinal transverse processes of L4 and L5 using software custom built at Chiba University Hospital (Fig. 3). This measurement was performed three times by each observer. A blinded evaluation was performed by three observers, and the average measurement was calculated. Reproducibility and accuracy of these measurements were evaluated before the current analysis.

Fig. 1 Anterior–posterior X-ray images. The angle of disc wedging (a, *), length of lateral slipping (a, **), and change in the angle between left and right bending (b, ***, ****) were evaluated with patients in a standing position. Length of lateral slipping (a, **) was the length between the inferior edge of L4 vertebra and superior edge of L5 vertebra using an anterior–posterior view from X-ray films

Fig. 2 Rotational mobility was determined by examining maximal left (a) and right rotation (b) on CT

Fig. 3 Rotational mobility (*, **) was measured using the spinal transverse processes of L4 and L5

Statistical analysis

Multivariate analysis and Spearman's correlation test were used to determine the relationship between factors. $P < 0.05$ was considered statistically significant.

Results

Evaluation of intervertebral discs

Characteristics of the patients and their degree of intervertebral disc degeneration are shown in Table 1. Of the ten patients in the control group, three showed grade 2 disc degeneration, three showed grade 3 disc degeneration, four showed grade 4 disc degeneration, and no patients showed grade 5 disc degeneration. Of the 32 patients in the L4–L5 disc-wedging group, MRI revealed 12 with grade 3 disc degeneration, 20 with grade 4 disc degeneration, and no patients with grade 5 disc degeneration. The 3D-CT reconstruction showed 3 instances of vacuum phenomena in the 10 patients in the control group and 25 instances of vacuum phenomena in the 32 patients in the L4–L5 disc-

wedging group. There was a significantly higher rate of vacuum phenomena in the L4–L5 disc-wedging group compared with the control group ($P < 0.05$).

X-ray image evaluation (Table 2)

Anterior–posterior X-ray images showed an average wedge angle of $0.5^\circ \pm 0.2^\circ$ (mean $\pm$ SEM) in the control group, and $5.3^\circ \pm 1.7^\circ$ in the L4/5 disc-wedging group, which was a significant difference ($P < 0.01$). Anterior–posterior X-rays also showed a significant difference in the length of lateral slip between the control group (0.6 ± 0.2 mm) and the L4–L5 disc-wedging group (1.5 ± 0.7 mm) ($P < 0.05$). There was a significant difference in the change in the angle between left and right bending, as demonstrated on two anterior–posterior views from X-ray films. The change in angle in the control group was $5.5^\circ \pm 1.3^\circ$, and $8.3^\circ \pm 1.9^\circ$ in the L4/5 disc-wedging group ($P < 0.05$).

CT evaluation for rotational mobility

The average rotational mobility on kinematic CT for the control group was $3.2^\circ \pm 0.8^\circ$, and $7.6^\circ \pm 1.7^\circ$ for the L4–L5 disc-wedging group. The rotational angle for the L4–L5 disc-wedging group was significantly higher than that in the control group ($P < 0.01$) (Table 2). In the L4–L5 disc-wedging group, the increase in the angle of disc wedging, seen on anterior–posterior X-rays, correlated with the rotational hypermobility determined from kinematic CT ($P < 0.01$) (Fig. 4). Furthermore, the increase in the change in angle between left and right bending, as determined from anterior–posterior X-ray film examinations in the L4–L5 disc-wedging group, correlated with an increase in rotational mobility on kinematic CT ($P < 0.01$) (Fig. 4).

Relationship between disc degeneration grade, vacuum phenomena, and rotational hypermobility

In the control group, there was no significant difference in the relationship between disc degeneration, vacuum

phenomenon, and rotational mobility evaluated by kinematic CT. In the L4–L5 disc-wedging group, there was no significant difference in the relationship between disc degeneration and rotational mobility; however, rotational mobility was significantly increased if vacuum phenomena existed in the L4–L5 disc compared to no vacuum phenomena ($P < 0.05$) (Table 2).

Discussion

To our knowledge, this is the first report evaluating rotational hypermobility of L4–L5 disc wedging using kinematic CT. We examined the rotational hypermobility of L4–L5 disc wedging in patients without antero- or retro-spondylolisthesis using kinematic CT. The average rotational mobility in the control group was 3.2° ; however, in patients with L4–L5 disc wedging, it was 7.6° . The rotational angle in the L4–L5 disc-wedging group was significantly higher than that in the control group ($P < 0.01$). The increase in the angle of disc wedging and change in the angle between left and right bending based on anterior–posterior X-rays correlated with the increase of rotational mobility by kinematic CT. The existence of vacuum phenomena in the L4–L5 disc increased rotational hypermobility. Some authors have reported on rotational instability of degenerative disc disease in vitro and in vivo using X-ray image, CT, and MRI examinations. However, there have been few studies measuring segmental rotation due to axial rotation in normal discs. In vitro and in vivo studies on axial rotation in normal discs have been reported. The in vitro data have suggested that the L4–L5 disc had 1.6° of axial rotation [15], while studies of in vivo data have reported 1.74° [6], 1.5° [19], and less than 1° for normal L4–L5 discs [13]. In the current study, the average rotational mobility determined by kinematic CT was $3.2^\circ \pm 0.8^\circ$ in the control group. This was larger than that determined in previous reports, but we used older controls (average age 69 years) who were age matched to the L4–L5 disc-wedging group. We speculated that disc

Table 2 Range of motion evaluated by X-ray and CT

	L4/5 disc-wedging group	Control group	Statistical analysis, <i>P</i>
X-ray evaluation			
Average angle of L4/5 disc	$5.3^\circ \pm 1.7^\circ$	$0.5^\circ \pm 0.2^\circ$	<0.01
Average length of lateral slipping	1.5 ± 0.7 mm	0.6 ± 0.2 mm	<0.05
Average change in angle between left and right bending	$8.3^\circ \pm 1.9^\circ$	$5.5^\circ \pm 1.3^\circ$	<0.05
CT evaluation for rotational mobility			
Average of rotational mobility	$7.6^\circ \pm 1.7^\circ$	$3.2^\circ \pm 0.8^\circ$	<0.01
Average of rotational mobility (vacuum phenomenon (–))	$5.6^\circ \pm 1.0^{**}$	$3.0^\circ \pm 0.6^\circ$	<0.01
Average of rotational mobility (vacuum phenomenon (+))	$8.8^\circ \pm 1.8^{***}$	$3.4^\circ \pm 0.9^\circ$	<0.01

*, ** $P < 0.05$

Fig. 4 The increase in the angle of disc wedging (a) and change in the angle between left and right bending (b) based on anterior–posterior X-rays correlated with an increase of rotational mobility by kinematic CT ($P < 0.01$)

degeneration was also occurring in the control group due to age, which then increased the rotational angle compared with data in previous reports.

The role of degenerated intervertebral discs in degenerative spinal instability has previously been clarified by means of biomechanical cadaver studies [5, 11, 14, 16, 17]. In one study on flexion–extension and axial rotation, the flexibility parameters increased with disc degeneration [11]. Another cadaver study revealed that axial rotational motion was most affected by disc degeneration rather than facet joints, and segmental motion increased with increasing severity of disc degeneration [5]. Blankenbaker et al. [3] have reported on the relationship of concordant pain by discography and the rotational instability of L4–L5 disc by kinematic CT evaluation in humans. On average, degenerated discs at L4–L5 with concordant pain rotated 1.9° , and those without concordant pain rotated 1.4° ($P = 0.05$). They concluded that determination of concordant pain by discography predicts increased axial rotation at the degenerated lumbar disc level. Haughton et al. [6] used MRI and a table device to produce small rotations of the torso, and reported average rotations for normal discs of 0.4° – 1.3° , and an average rotation of 2.2° for abnormal discs with concordant pain. This difference in rotation between abnormal and normal discs was statistically significant.

When ruptures of the annulus fibrosus occur, such as radial and transverse tears of the annulus fibrosus, resistance to rotation in the axial plane is markedly diminished

[1, 7, 22]. Radial and transverse tears of the annulus fibrosus have a greater effect on motions produced by axial rotatory torque than on those produced by flexion, extension, or lateral bending torque. The difference between normal discs and discs with annular tears is also more marked during moments of axial rotational than during those of flexion, extension, or lateral bending. One study showed that under 5.7 N m axial rotation torque, motions were 5.2° for transverse tears and 5.1° for radial tears [7]. The presence of a high-intensity zone in the intervertebral disc was associated with reduced stiffness of motion segments. This reduction was greater in cases of axial rotation than for other torques [22]. We found an average rotation of $7.6^\circ \pm 1.7^\circ$ in the L4–L5 disc-wedging group. Degenerated disc wedging is accompanied by radial and transverse tears. In the current study, there was also a high rate of vacuum phenomena in the L4–L5 disc-wedging group that significantly increased the rotational mobility. The similarity in rotational hypermobility between our study and previously reports is likely due to the relatively severe degree of disc degeneration.

As an indication for fusion, radiographic evaluation of instability with lateral radiographs of the spine in flexion and extension is widely used. However, the current study revealed that patients in the L4–L5 disc-wedging group, who were without antero- or retrospondylolisthesis, also had axial rotational instability. Mimura [10] reported a range of rotational motion of 2° – 3° at each motion segment in the normal lumbar spine; however, the rotational motion

was significantly larger in cases of spondylolysis, spondylolisthesis, and degenerative spondylolisthesis. He also reported rotational instability of about 6.5° at the L4–L5 level in patients with an average of 17% anterospodylolisthesis [10]. In the present case, rotational hypermobility of 7.6° in patients with L4–L5 disc wedging but no anterior retrospondylolisthesis corresponded to the rotational instability of 17% seen in cases of anterospodylolisthesis. Thus, it is important to consider rotational hypermobility in L4–L5 disc wedging for surgical planning. The use of kinematic CT, or, at the very least, X-ray findings of lateral bending positions, is needed for confirmation.

There are some limitations to the current study. First, the number of patients was small. Second, “maximal rotation” on CT evaluation may be different for each patient, though we defined the “maximal rotation” as described in “Patients and methods”. Third, we did not measure the facet angle in the current study. However, we believe that facet angle is also important for rotational mobility. In this regard, more precise methods and further study are needed to strengthen our hypothesis.

In conclusion, we evaluated the rotational mobility of L4/5 disc wedging in patients without spondylolisthesis using kinematic CT. The average rotational mobility in the L4–L5 disc-wedging group was 7.6° compared to the control group at 3.2° , which was a significant difference. The increase in the angle of disc wedging and the change in the angle between left and right bending as seen by anterior–posterior X-rays, and the appearance of vacuum phenomena in the L4–L5 discs all correlated with the increased rotational mobility determined by kinematic CT.

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