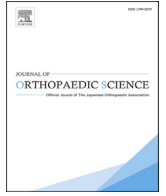




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Original Article

Age-related changes in axial and sagittal orientation of the facet joints: Comparison with changes in degenerative spondylolisthesis

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ABSTRACT

Background: Despite facet joints being three-dimensional structures, previous computed tomography and magnetic resonance imaging studies have evaluated facet joint orientation in only the axial plane. Facet joint orientation in the sagittal plane has rarely been studied using these imaging techniques. The aim of this study was to elucidate facet joint orientation in both the axial and sagittal planes on computed tomography.

Methods: A total of 568 patients (343 men, 225 women) (excluding orthopedic outpatients) for whom abdominal and pelvic computed tomography scans were obtained at our hospital between September 2010 and October 2012 were included. Mean age was 63 (range 21–90) years. Patients were divided into a degenerative spondylolisthesis group (67 patients; 30 men, 37 women) and a control group (313 patients; 313 men, 188 women). Facet joint orientation was evaluated in the control group according to patient age (≤ 50 , 51–60, 61–70, or ≥ 71 years). The findings in the control group were then compared with those in the degenerative spondylolisthesis group. The orientation of the lumbar facet joints at each level was measured in the axial and sagittal planes on computed tomography images.

Results: Facet joint angles decreased with age at L4/5 and L5/S1 in women in the axial plane and at L4/5 in men and L3/4 and L4/5 in women in the sagittal plane. The variation in facet joint angle was greatest at L4/5 in women. Patients with degenerative spondylolisthesis showed more sagittally and horizontally oriented facet joints in the axial and sagittal planes; facet tropism showed an association with degenerative spondylolisthesis in the axial plane.

Conclusions: The axial and sagittal orientation of facet joints in the lower lumbar vertebra, especially L4/5, was negatively correlated with age. This finding could help to explain why older people are more prone to degenerative spondylolisthesis.

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1. Introduction

Degenerative spondylolisthesis is common in the elderly population and is one of the most common indications for spinal surgery in older adults [1,2]. The facet joints provide posterior mechanical support that protects the motion segments from

anterior shear forces and from excessive rotation and flexion [3,4]. Some researchers have reported that one of the causes of degenerative spondylolisthesis is degeneration of the facet joints, in particular sagittalization of the facet joints in the axial plane [5–10]. Furthermore, there are studies suggesting that the facet joints become more sagittal in the axial plane with advancing age [10,11]. Although a number of studies have investigated the orientation of the facet joints in the axial plane using computed tomography (CT) or magnetic resonance imaging (MRI), there is still limited information available on the orientation of the facet joints in the sagittal plane using these modalities [8,10]. We hypothesized that it would be important to evaluate the orientation of

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the facet joints not only in the axial plane but also in the sagittal plane, given that the facet joints are three-dimensional structures. To our knowledge, CT reconstruction studies of the correlation between orientation of the facet joints in the axial and sagittal planes and age have not been reported.

The primary aim of this study was to clarify the relationship between orientation of the facet joints and age in both the axial and sagittal planes using CT. A secondary aim was to improve our understanding of changes in facet joint morphology by comparing a group of control subjects (without degenerative spondylolisthesis, spondylolysis, or spondylolytic spondylolisthesis) and a group of patients with degenerative spondylolisthesis.

2. Materials and methods

This research has been approved by the IRB of the authors' affiliated institutions. In order to evaluate the general public, we identified 628 patients (excluding orthopedic outpatients) who had undergone abdominal and pelvic CT scanning between September 2010 and January 2012 at our hospital. Patients with a history of spondylolysis, spondylolytic spondylolisthesis, previous back surgery, or metastasis to the lumbar vertebra were excluded, leaving data for 568 patients of mean age 63 (range 21–90) years for inclusion in the analysis. These patients were divided into a control group and a degenerative spondylolisthesis group (see Table 1). Thirty-two patients (18 men, 14 women) with compression fracture and Eighty-four patients (39 men, 45 women) with a scoliosis of Cobb angle more than 10° were included in a control group. Spondylolisthesis was judged to be present if the vertebral shift was >7% of the anteroposterior diameter of the inferior vertebra.

As shown in Table 2, we investigated the orientation of the facet joints in the control group when divided into the following age groups: ≤50 years (40 men, 38 women); 51–60 years (69 men, 49 women); 61–70 years (116 men, 55 women); and ≥71 years (83 men, 46 women). We then compared the findings in the control group with those in the degenerative spondylolisthesis group. The spinal level most affected by degenerative spondylolisthesis was L4/5, so all comparisons between the two patient groups were made at this level.

2.1. Facet joint orientation in the axial plane

Facet joint angles were measured in the axial plane using the method described by Noren et al. [12]. On an axial scan that bisected the intervertebral disc, a line was drawn between the anteromedial and posterolateral aspects of each facet joint and another line was drawn in the midsagittal plane of the vertebra (Fig. 1A). The degrees of the two angles (right and left) were averaged. A smaller angle in the axial plane indicated that the facet joint was sagittally oriented. Facet joint tropism was diagnosed when the difference between the orientation of the left and right facet joint was greater than 7° in both the axial and sagittal planes.

Table 1
Prevalence of degenerative spondylolisthesis.

	Men	Women	Sex ratio	p value
Control (n [%])	313 (91.3)	188 (83.6)		
Degenerative spondylolisthesis (all) (n [%])	30 (8.7)	37 (16.4)	1: 1.8	0.005
Degenerative spondylolisthesis (L4/5) (n [%])	19 (5.5)	28 (12.4)	1: 2.0	0.003
Total	343	225		

Table 2

Age distribution in 313 men and 188 women in the control group. The control group were divided according to age as follows: ≤50 years (45 men, 38 women); 51–60 years (69 men, 49 women); 61–70 years (116 men, 55 women); ≥71 years (83 men, 46 women).

Age	male	female	Total
20–50	45	38	83
51–60	69	49	118
61–70	116	55	171
≥71	83	46	129
Total	313	188	501

2.2. Facet joint orientation in the sagittal plane

The facet joint angles were measured in the sagittal plane. On a sagittal scan that bisected each facet joint, a line was drawn between the anterosuperior and posteroinferior aspects of each facet joint, and thereafter a line was drawn on the bisected intervertebral disc (Fig. 1B). The degrees of the two angles (right and left) were averaged. A smaller angle in the sagittal plane indicated that the facet joint was horizontally oriented. Facet joint tropism was diagnosed when the difference between the orientation of the left and right facet joint was greater than 7° in both the axial and sagittal planes.

2.3. CT images

Each CT scan image was reconstructed using 1-mm-thick slices with an Aquarius NET Server (TeraRecon, Inc., Foster City, CA). Presence of disease was confirmed in multiple planes, including replanning of axial and oblique axial images. To estimate the intraobserver and interobserver reliability, measurements were taken twice by two independent observers (general orthopedic surgeon (MM), who had about 10 years' experience, and certified spine surgeon (KH), who had more than 20 years' experience) in 60 patients chosen at random.

2.4. Statistical analysis

The statistical analysis was performed using SPSS version 21.0 software (IBM Corp., Armonk, NY). The Student's *t*-test was used for normally distributed data. Nominal variables were tested with the Pearson's chi-square test. One-way analysis of variance and Tukey's honestly significant difference test were used for comparisons between more than two groups. Simple kappa coefficients (κ) were calculated to describe interobserver and intraobserver agreement. A post hoc power analysis was performed. The correlation analysis was performed with the Pearson method. A *p*-value <0.05 was considered statistically significant.

3. Results

3.1. Interobserver and intraobserver agreement

The both interobserver and intraobserver agreements for the facet joint angle measurement were excellent (axial plane; $\kappa = 0.93$ and $\kappa = 0.90$, respectively; sagittal plane; $\kappa = 0.90$ and $\kappa = 0.87$, respectively).

3.2. Facet joint orientation in the axial plane

The facet joint angles in the axial plane did not change with age in men (Fig. 2). However, the angles decreased with age in the lower lumbar spine in women, especially at L4/5 and L5/S1; there

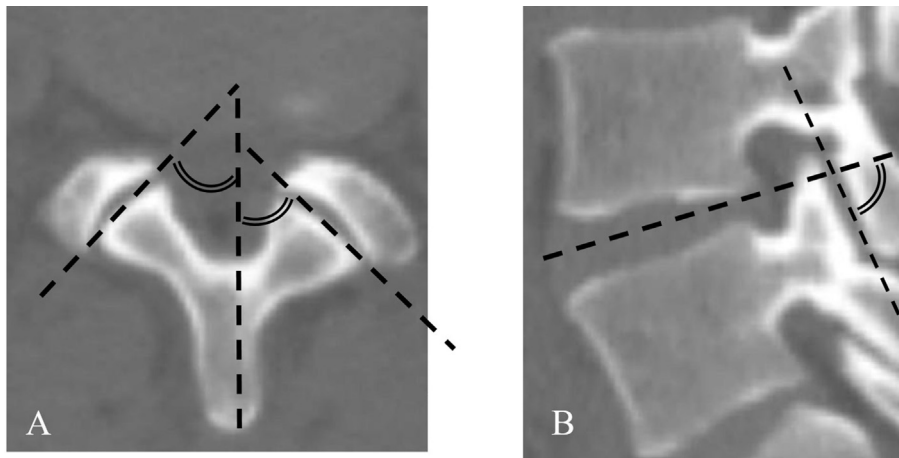


Fig. 1. Facet joint angles in axial (A) and sagittal (B) views.

were statistically significant differences at L4/5 between the group aged ≤ 50 years and the group aged ≥ 71 years ($p = 0.005$), and at L5/S1 between the group aged ≤ 50 years and the group aged ≥ 71 years ($p = 0.008$) (Fig. 3).

3.3. Facet joint orientation in the sagittal plane

The facet joint angles in the sagittal plane decreased with age in the lower lumbar spine in men, with a statistically significant difference at L3/4 between the group aged ≤ 50 years and the group aged 61–70 years ($p = 0.006$), and at L4/5 between the group aged ≤ 50 years and the group aged 61–70 years ($p = 0.019$) (Fig. 4). The facet joint angles also decreased at the lower lumbar spine levels in women, with statistically differences found at L2/3 between ≤ 50 years and the group aged > 71 years ($p = 0.002$), at L3/4 between the group aged ≤ 50 years and the group aged 51–60 years ($p = 0.008$), between the group aged ≤ 50 years and the group aged 61–70 years ($p = 0.012$), and between the groups ≤ 50 years and the group aged ≥ 71 years ($p = 0.000$), and at L4/5 between the group aged ≤ 50 years and the group aged 61–70 years ($p = 0.003$), between the group aged < 50 years and the group aged ≥ 71 years

($p = 0.000$), and between the group aged 51–60 years and the group aged ≥ 71 years ($p = 0.000$) (Fig. 5). The facet joint angles also decreased at the upper lumbar spine levels (L1/2, L2/3) in the sagittal plane in women, but not significantly.

3.4. Comparison of control and degenerative spondylolisthesis groups

The degenerative spondylolisthesis rate was 8.7% in men and 16.4% in women (Table 1). The spinal level most affected by degenerative spondylolisthesis was L4/5 (at a rate of 5.5% in men and 12.4% in women).

The facet joint orientation at L4/5 was significantly more sagittal and horizontal in the degenerative spondylolisthesis group than in the control group (Table 3). Facet joint tropism was found in the axial plane at L4/5 in 42.6% of patients in the degenerative spondylolisthesis group and in 27.3% of subjects in the control group ($p = 0.027$, chi-square test). However, there was no significant difference in facet joint tropism at L4/5 in the sagittal plane between the two groups.

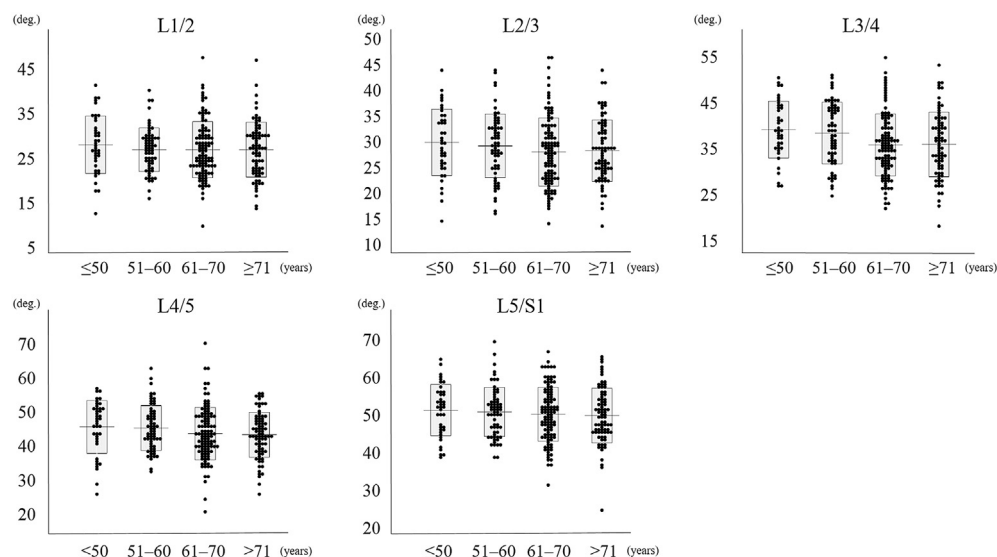


Fig. 2. Change in orientation of the facet joints at each level of the lumbar spine on axial views according to age in men.

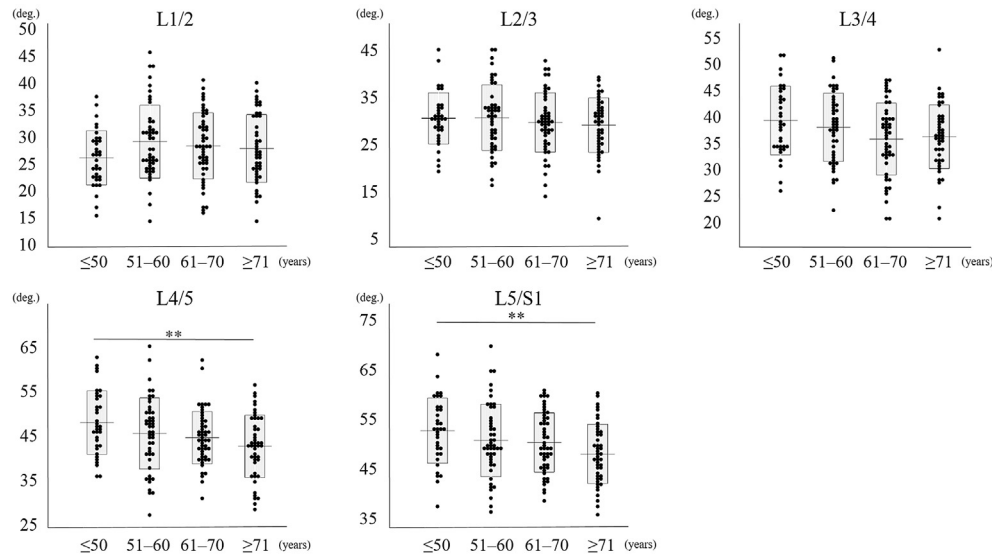


Fig. 3. Change in orientation of the facet joints at each level of the lumbar spine on axial views according to age in women. ** $p < 0.01$, Tukey's honestly significant difference test.

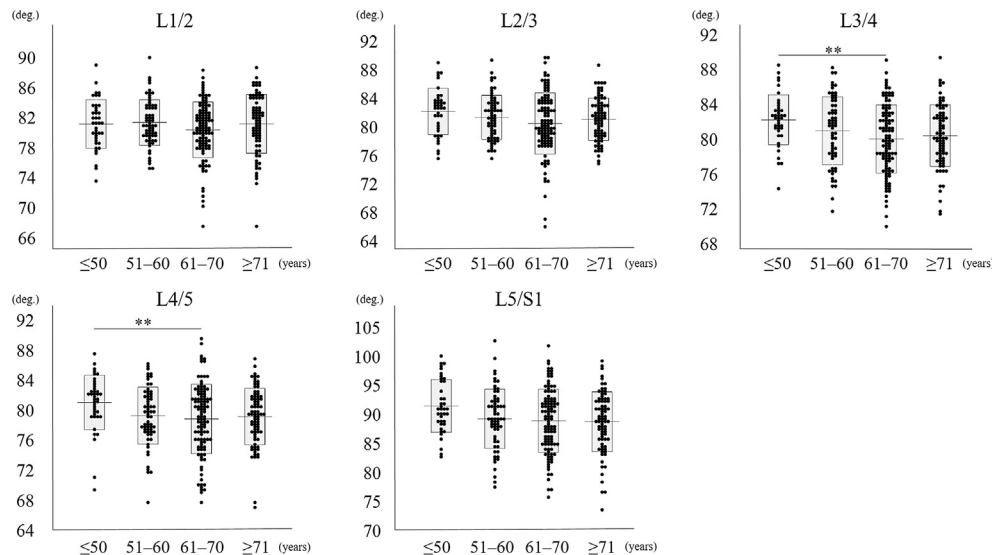


Fig. 4. Change in orientation of the facet joints at each level of the lumbar spine on sagittal views according to age in men. ** $p < 0.01$ Tukey's honestly significant difference test.

3.5. Correlation between facet joint orientation in the axial and sagittal planes

There was a correlation between facet joint orientation in the axial plane and that in the sagittal plane at L3/4 and L4/5 ($r = 0.410$, $p < 0.001$ and $r = 0.333$, $p < 0.001$ respectively; Fig. 6).

4. Discussion

The main findings of this study were as follows: the facet joint angles decreased significantly with increasing age at L4/5 and L5/S1 in the axial plane and at L3/4 and L4/5 in the sagittal plane in women; the facet joint angles decreased significantly with age at L4/5 in the sagittal plane in men; the facet joint angle most affected by age in women was L4/5; the facet joint angle in patients with degenerative spondylolisthesis was decreased in both the axial and sagittal planes and facet joint tropism was significantly increased in

comparison with controls; and there was a correlation between facet joint angles in the axial plane and those in the sagittal plane.

Wang et al. reported that the orientation of the facet joints at L4/5 became more sagittal in the axial plane with increasing age [10]. To our knowledge, there has been no report concerning orientation of the facet joints at each lumbar level with age using the sagittal plane on CT or MRI. In this study, we found that the facet joint angles decreased with age not only in the axial plane but also in the sagittal plane in both sexes. Interestingly, this change in facet joint orientation occurred at the lower lumbar levels but not at the upper lumbar levels, indicating that the shape of the facet joint in the lower lumbar spine makes it more prone to slipping. Moreover, we found that this change in orientation was more common at the L4/5 level in women than in men. This finding is consistent with reports in the literature showing that degenerative spondylolisthesis occurs most often at L4/5 and predominantly in women [6,13,14]. Our results are similar to those of previous studies in that we found a male to female ratio of 1:1.8 and a prevalence of degenerative

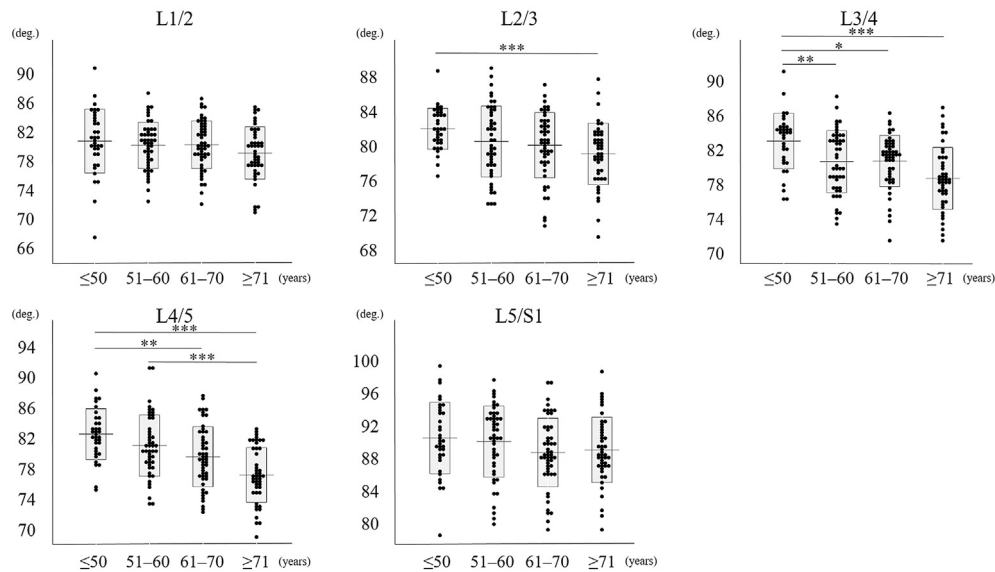


Fig. 5. Change in orientation of the facet joints at each level of the lumbar spine on sagittal views according to age in women * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Tukey's honestly significant difference test.

Table 3

Comparison of controls and degenerative spondylolisthesis at L4/5. The Student's *t*-test was used for facet orientation data. Facet tropism was tested with the Pearson's chi-square test. Statistically significant differences at $P < 0.05$ are marked in bold.

	Control	Degenerative spondylolisthesis at L4/5	p value
Facet orientation (axial view) (deg.)			
L1/2	27.4 ± 6.0	26.2 ± 5.2	0.72
L2/3	29.0 ± 7.2	27.5 ± 5.4	0.27
L3/4	37.3 ± 7.3	36.3 ± 6.2	0.24
L4/5	44.6 ± 7.2	41.8 ± 8.4	0.00
L5/S1	50.8 ± 7.0	53.0 ± 5.0	0.22
Facet tropism (axial view) (%)			
L1/2	22.6	25.5	0.87
L2/3	21.8	23.4	0.55
L3/4	16.8	14.9	0.74
L4/5	27.3	42.6	0.03
L5/S1	28.3	34	0.41
Facet orientation (sagittal view) (deg.)			
L1/2	81.1 ± 3.6	80.7 ± 3.8	0.93
L2/3	81.1 ± 4.5	79.3 ± 3.1	0.05
L3/4	80.7 ± 4.2	77.1 ± 3.8	0.00
L4/5	79.5 ± 4.1	75.9 ± 3.7	0.00
L5/S1	89.5 ± 5.3	89.2 ± 5.3	0.67
Facet tropism (sagittal view) (%)			
L1/2	21.8	23.4	0.79
L2/3	8	10.6	0.53
L3/4	9.6	8.5	0.81
L4/5	8.2	14.9	0.12
L5/S1	12.6	12.8	0.97

spondylolisthesis at L4/5 of 67.2%. The finding that facet joint orientation at L4/5 is more prone to becoming sagittal and horizontal with increasing age in women points to one of the risk factors for degenerative spondylolisthesis.

Some authors have attempted to explain the causes of changes in facet joint orientation. Boden et al. reported that disc degeneration lead to a change in facet joint orientation [5], whereas Fujiwara et al. and Kalichman et al. proposed osteoarthritis of the lumbar facet joints as a factor associated with change in facet joint orientation [8,15]. In the present study, there were significant positive correlations between facet joint orientation in the axial and sagittal planes at L3/4 and L4/5 ($r = 0.410$, $p < 0.001$ and

$r = 0.333$, $p < 0.001$ respectively). To the best of our knowledge, this is the first time that sagittalization and horizontalization of the facet joints were found to proceed in relation to each other.

Several studies have reported that facet joints with degenerative spondylolisthesis are more sagittally orientated in the axial plane [5,6,16,17]. However, there is limited information on facet joint orientation in the sagittal plane, so the association between facet joint orientation in the sagittal plane and spondylolisthesis remains unclear. There is only one report on facet joint orientation in the sagittal plane on CT, in which Gao et al. reported that the orientation of the facet joints in slipped vertebra was more horizontal [18]. However, only 156 patients were included in that study and all had undergone CT to investigate low back pain or sciatica. In our present study, the sagittal change in the facet joints in the axial plane occurred at the L4/5 level in patients with degenerative spondylolisthesis. Moreover, we found that the facet joints were more horizontally orientated in the sagittal plane in the patients with degenerative spondylolisthesis than in the controls.

Boden et al. also reported that the mean orientation of the lumbar facet angles in patients with degenerative spondylolisthesis was more sagittal at levels adjacent to the slip [5]. In our study, we found no significant differences in the facet joint angles between L3/4 and L5/S1 in the axial plane, but did find a significant difference in the angles at L3/4 in the sagittal plane.

Studies related to facet joint tropism in patients with degenerative spondylolisthesis have yielded conflicting results. Dai reported that patients with degenerative spondylolisthesis had more significant facet joint tropism in the axial plane than control subjects and that the facet joint tropism was significantly correlated with the degree of disc degeneration. Therefore, he suggested that facet joint tropism was a predisposing factor for development of disc degeneration and subsequent spondylolisthesis [16]. However, Berlemann et al. and Kalichman et al. found no relationship between facet joint tropism and development of degenerative spondylolisthesis [6,11]. In the present study, facet joint tropism at L4/5 in patients with degenerative spondylolisthesis was significantly increased in the axial plane. On the other hand, concerning facet joint tropism in the sagittal plane, Gao et al. reported that facet joint tropism correlated well with degenerative spondylolisthesis [18]. However, in our study, there was no relationship between facet

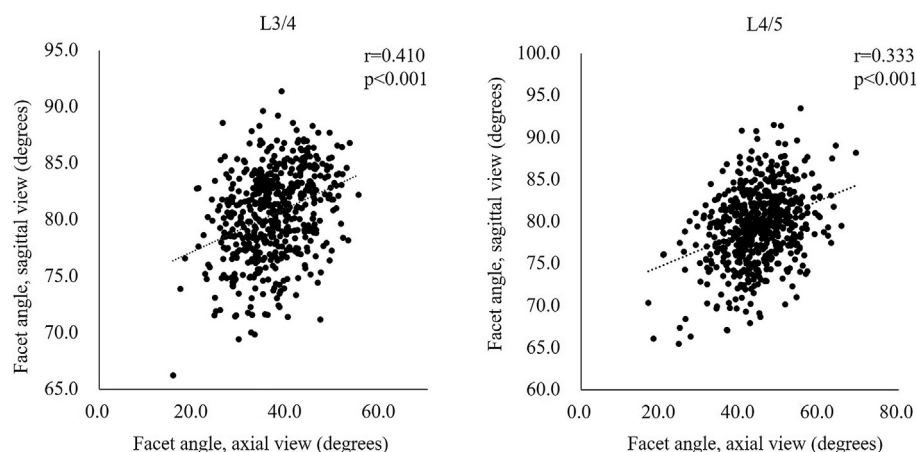


Fig. 6. Relationship between the facet joint angle on axial and sagittal views at L3/4 and L4/5.

Table 4

Comparison of controls and compression fracture. The Student's *t*-test was used for facet orientation data.

	Control Without compression fracture	compression fracture	p value
Facet orientation (axial view) (deg.)			
L1/2	27.5 ± 6.0	28.8 ± 7.1	0.32
L2/3	29.1 ± 7.0	28.5 ± 5.4	0.38
L3/4	37.4 ± 6.8	35.9 ± 5.7	0.24
L4/5	44.6 ± 7.1	45.0 ± 7.0	0.90
L5/S1	50.9 ± 7.1	50.1 ± 6.3	0.56
Facet orientation (sagittal view) (deg.)			
L1/2	81.2 ± 3.6	80.1 ± 3.1	0.28
L2/3	81.2 ± 4.2	81.6 ± 3.8	0.35
L3/4	80.8 ± 3.8	81.5 ± 3.0	0.27
L4/5	79.6 ± 4.1	79.3 ± 3.6	0.46
L5/S1	89.6 ± 5.2	89.6 ± 4.4	0.94

joint tropism and degenerative spondylolisthesis in the sagittal plane.

The present study has several limitations. Since we focused on degenerative spondylolisthesis in this study, we included several diseases, such as compression fracture and degenerative scoliosis, into control group. Regarding to compression fracture, we found that there were no significant difference between the facet joint orientation in compression fracture and the control group (Table 4). In regards to degenerative scoliosis, since it is possible that facet joint orientation will change depending on the degree of scoliosis, it is necessary to investigate the facet joint orientation in degenerative scoliosis in the future. In view of the cross-sectional design of our study, we cannot conclude whether sagittally or horizontally orientated joints predispose to development of degenerative spondylolisthesis. However, we did find sagittalization and horizontalization of the facet joints in older patients and in those with degenerative spondylolisthesis. Therefore, we suspect that sagittalization and horizontalization of the facet joints leads to degenerative spondylolisthesis. This hypothesis will need to be tested in a longitudinal study in the future.

5. Conclusions

This study showed that facet joint angle decreases with increasing age at L4/5 and L5/S1 in the axial plane in women, at L4/5 in the sagittal plane in men, and at L3/4 and L4/5 in the sagittal plane in women. Sagittalization and horizontalization of

the facet joints was found in patients with degenerative spondylolisthesis. Facet joint tropism was greater at L4/5 in the axial plane in patients with degenerative spondylolisthesis than in controls.

Conflicts of interest

None.

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