ORIGINAL

Evaluation of segmental mobility in patients with lumbar spondylolisthesis : A comparison of images from standing flexion-extension and standing/supine slippage

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Abstract : Purpose : To evaluate segmental mobility with degenerative lumbar spondylolisthesis (DLS), upright lateral flexion-extension radiographs (FE) are widely used. However, some authors have described that a combination of lateral radiographs in the standing position and supine sagittal image (SS) reveal more segmental mobility than FE. The purpose of this study was to investigate the optimal method for evaluating segmental mobility with DLS. Methods : We included 92 consecutive Japanese patients diagnosed with DLS. Sagittal translation (ST) determined by FE and SS were compared. Pathological instability was defined as ST more than 8% of the upper vertebra. Patients were divided into those diagnosed with pathological instability in FE (PI-FE) and those diagnosed with SS (PI-SS), and lumbar lordosis (LL) in the standing position in each group were compared. Results : ST in FE was significantly greater than in SS. Of 92 patients, 31 had pathological instability in FE or SS ; 17 patients had PI-FE, and 10 patients had PI-SS. LL in the standing position in PI-FE was significantly smaller than in PI-SS. Conclusions : ST in FE was greater than that in SS, contrary to previous studies' reports on Caucasians. Since Japanese individuals have smaller LL than Caucasians, FE tends to reveal more segmental mobility than SS. J. Med. Invest. 70 : 135-139, February, 2023

Keywords **:** *lumbar spondylolisthesis, segmental mobility, spinal instability, flexion-extension radiographs, magnetic resonance images*

INTRODUCTION

In lumbar spondylolisthesis, various diagnostic modalities for evaluating instability have been reported (1-4). However, the optimal diagnostic modality for evaluating abnormal segmental mobility is unknown. Currently, due to its simple usage and low cost, upright lateral flexion-extension radiographs (FE) are widely used in most facilities (5, 6).

However, functional radiographs are occasionally too demanding as they require patients' efforts and cooperation. Particularly, patients with low back pain might be unable to flex or extend their lumbar spine sufficiently (7). Therefore, some authors have described that a combination of lateral radiographs in the standing position and supine sagittal image (SS) taken using computed tomography (CT) (3) or magnetic resonance imaging (MRI) (4) reveal more segmental mobility than FE in patients with lumbar spondylolisthesis. In these reports, the mean segmental mobility of SS was larger than that of FE, but the evaluation method that could reveal segmental mobility depends on each patient (3, 4). Although physical constitution, such as height or body mass index (BMI), correlated with segmental mobility, factors associated with increased mobility in FE and SS were uncertain (3, 4).

This study aimed to compare segmental mobility and to identify factors associated with the difference between FE and SS obtained using MRI.

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MATERIALS AND METHODS

This was a retrospective study of 92 consecutive Japanese patients (34 male ; 58 female patients ; mean age, 71.2 [42–88] years) who were diagnosed with L4-5 degenerative lumbar spondylolisthesis and underwent surgery at our hospital between January 2010 and December 2016. The exclusion criteria included previous thoracolumbar spine surgery, multilevel lumbar spondylolisthesis, retrolisthesis, ankylosing spondylitis, and severe scoliosis (Cobb angle ≥ 10°). Written informed consent was obtained from all study participants. The ethics committee of our university approved all protocols used in this study (Approval number 292-183).

All patients underwent upright lateral radiographs, FE and MRI examinations. The distance between the X-ray source and the patient during the upright lateral radiograph examinations and FE was 1.15 meters. During the FE, patients were instructed to flex and extend their lower back as far as possible. MRI was performed using a spine coil with a GE Signa HDx 1.5T (GE Healthcare, Milwaukee, WI). These images were taken for patients with lumbar spondylolisthesis preoperatively.

Segmental mobility was identified by measuring sagittal translation (ST) at L4–5 in each patient. ST was measured according to a method described by Dupuis *et al*. (8) (Figure 1). First, the slippage in each position (flexion, extension, standing, and supine) was measured. Subsequently, ST in FE and ST in SS were calculated. ST was analyzed in absolute values and relative values, which is the percentage of the upper vertebral body width. In this study, an ST of more than 8% of the width of the upper vertebral body was considered to indicate pathological instability, as defined by Dupuis *et al*. (8). The absolute and relative values of ST observed in FE were compared with those observed in SS. Furthermore, to identify factors associated with increased mobility in FE and SS, patients were divided into

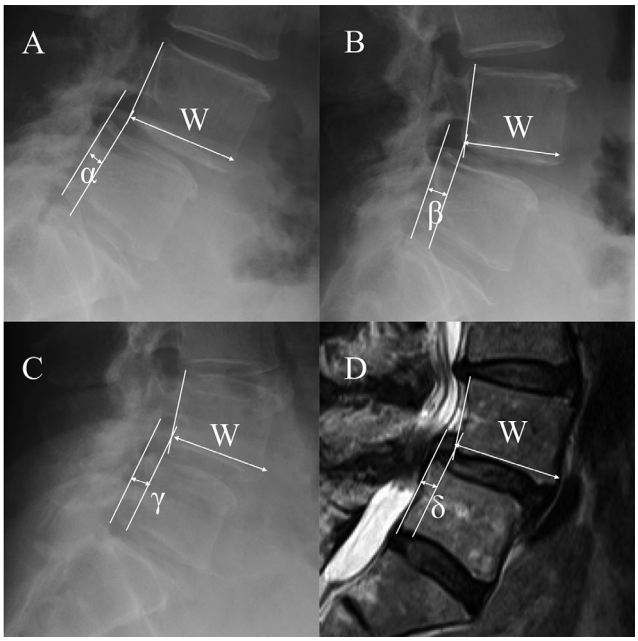


Fig 1. Measurement of sagittal translation (ST)
A : Flexion radiograph. B : Extension radiograph. C : Upright radiograph. D : Supine magnetic resonance image
α : Slippage in flexion β : Slippage in extension. γ : Slippage in standing position δ: Slippage in the supine position. W : Width of the upper vertebral body
Absolute value of ST in flexion-extension radiograph = α-β, relative value of ST in flexion-extension radiograph = (α-β) / W*100
The absolute value of ST in a combination of lateral radiograph in a standing position and supine sagittal image = γ-δ, the relative value of ST in a combination of lateral radiograph in a standing position and supine sagittal image = (γ-δ) / W*100

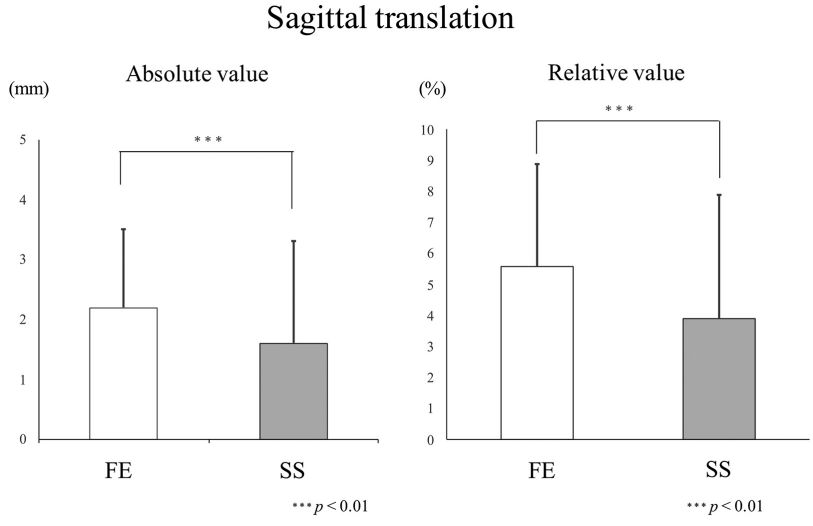
two groups : those diagnosed with pathological instability in FE (PI-FE) and those diagnosed with SS (PI-SS). Age, sex, height, weight, BMI, slippage grade (Meyerding grading system), lumbar lordosis (LL) in the standing and supine positions, and relative values of the slippage in each position were compared between the two groups. The amount of change of LL in lumbar flexion and extension were compared to investigate whether patients could flex or extend their lumbar vertebrae sufficiently. Furthermore, the relationship between physical constitution and ST was studied by correlating the relative values of ST in FE, ST in SS, and LL in standing position.

Statistical analysis was performed using a *t*-test to compare averages of continuous variables. Chi-square test was used to compare the proportions of categorical variables between the two groups. Spearman's correlation coefficient was used to determine the relationship between ST in FE, ST in SS, and LL in the standing position. The threshold for significance was set at $p < 0.05$. All statistical analyses were conducted using IBM Statistical Package for the Social Sciences version 27.0 software (IBM Corp., Armonk, N.Y., USA).

RESULTS

The patients' mean height was 154.9 cm (131.5–178.9 cm), mean weight was 59.3 kg (35.6–94.5 kg), and the mean BMI was 24.7 (15.8–40.6). The average of the absolute and relative value of ST was significantly greater in FE than in SS (2.2 ± 1.3 mm vs. 1.6 ± 1.7 mm, $p < 0.01$ and 5.6 ± 3.3% vs. 3.9 ± 4.0%, $p < 0.01$, respectively, Fig 2). Out of 92 patients, 31 were diagnosed with pathological instability only in FE or SS. Seventeen patients were diagnosed with pathological instability in FE (PI-FE), 10 patients were diagnosed using SS (PI-SS), and four patients were diagnosed using both FE and SS.

The differences in age, sex, weight, slippage grade, and LL in



FE: upright lateral flexion-extension radiographs
SS: combination of lateral radiograph in a standing position and supine sagittal image

Fig 2. Mean of absolute (left) and relative (right) value of sagittal translation

the supine position between the PI-FE and PI-SS groups were statistically insignificant (Table 1). However, LL in the standing position in PI-FE was significantly smaller than in PI-SS (39.4 ± 12.2° vs. 49.4 ± 11.7°, p = 0.04). The relative values of the slippage in flexion and supine position were significantly greater in PI-FE than in PI-SS (22.1 ± 4.9% vs. 17.1 ± 6.1%, p = 0.02, and 13.2 ± 4.4% vs. 7.9 ± 4.5%, p < 0.01, respectively, Table 2). There were no statistically significant differences in the slippage in extension and in the standing position (12.2 ± 4.7% vs. 12.7 ± 5.9%, p = 0.78 and 16.0 ± 5.1% vs. 17.3 ± 4.8%, p = 0.49, respectively, Table 2). Furthermore, there were no statistically significant differences in the amount of change of LL in flexion and extension (17.9 ± 10.9° vs. 15.2 ± 11.0°, p = 0.54 and 8.5 ± 6.4° vs. 2.1 ± 11.1°, p = 0.07, respectively, Table 3). There was a moderate negative correlation between LL on standing position and ST in FE (r = -0.43, p = 0.02, Fig 3). However, there was no correlation between LL in the standing position and ST in SS (r = 0.12, p = 0.52, Fig 3).

DISCUSSION

Accurate evaluation of segmental mobility is critical for managing lumbar spondylolisthesis. Some recent reports have shown that SS reveals more mobility than FE (3, 4, 9) because the relaxed supine position can facilitate the reduction of segments with anterolisthesis. However, in this study, both the absolute and relative values of ST in FE were greater than those in SS.

Table 1. Comparison of demographic data between PI-FE and PI-SS

		PI-FE (n = 17)	PI-SS (n = 10)	P-value
Age (y)		68.0 ± 12.3	75.5 ± 10.7	0.12
Sex (male : female)		11 : 6	4 : 6	0.21
Height (cm)		153.0 ± 7.8	158.5 ± 6.8	0.07
Weight (kg)		60.6 ± 9.4	60.6 ± 6.2	0.98
Body mass index (kg/m^2)		25.8 ± 2.9	24.0 ± 0.9	0.07
Meyerding grade	1	16 (94%)	10 (100%)	0.43
	2	1 (6%)	0	
Lumbar lordosis in standing position (°)		39.4 ± 12.2	49.4 ± 11.7	0.04
Lumbar lordosis in supine position (°)		42.6 ± 12.0	48.1 ± 7.5	0.20

PI-FE : patients diagnosed with pathological instability in upright lateral flexion-extension radiographs
PI-SS : patients diagnosed with pathological instability through a combination of lateral radiograph in the standing position and supine sagittal position image.

Table 2. Comparison of relative value of the slippage between PI-FE and PI-SS

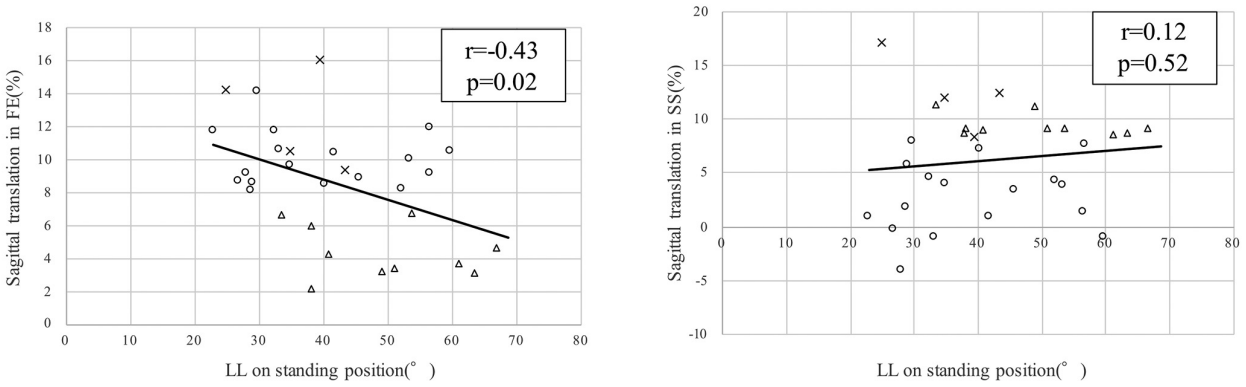
	PI-FE (n = 17)	PI-SS (n = 10)	P-value
Flexion (%)	22.1 ± 4.9	17.1 ± 6.1	0.02
Extension (%)	12.2 ± 4.7	12.7 ± 5.9	0.78
Standing position (%)	16.0 ± 5.1	17.3 ± 4.8	0.49
Supine position (%)	13.2 ± 4.4	7.9 ± 4.5	<0.01

PI-FE : patients diagnosed with pathological instability in upright lateral flexion-extension radiographs
PI-SS : patients diagnosed with pathological instability through a combination of lateral radiograph in the standing position and supine sagittal position image.

Table 3. The amount of change of lumbar lordosis in flexion and extension

	PI-FE (n = 17)	PI-SS (n = 10)	P-value
Flexion (°)	17.9 ± 10.9	15.2 ± 11.0	0.54
Extension (°)	8.5 ± 6.4	2.1 ± 11.1	0.07

PI-FE : patients diagnosed with pathological instability in upright lateral flexion-extension radiographs
PI-SS : patients diagnosed with pathological instability through a combination of lateral radiograph in the standing position and supine sagittal position image.



○Pathological instability in FE △Pathological instability in SS ×Pathological instability in both FE and SS

FE: upright lateral flexion-extension radiographs
SS: combination of lateral radiograph in a standing position and supine sagittal image
LL: lumbar lordosis

Fig 3. Correlation between lumbar lordosis in the standing position and sagittal translation (ST) in upright lateral flexion-extension radiographs (left), ST in a combination of lateral radiograph in the standing position and supine sagittal image (right)

A reason for the conflicting results between this study and those of previous studies could be the racial differences among subjects. In previous studies, most patients investigated were Caucasians, whereas all patients in this study were Japanese. Liu N *et al*. (4) reported that ST in SS correlated with BMI positively, and ST in FE correlated with height negatively. The height and BMI of patients in this study were lower than those in a previous study (4). Furthermore, LL in the standing position in PI-FE was lower than that in PI-SS, and there was a moderate negative correlation between LL in the standing position and ST in FE. Le Huec *et al*. (10) reported that LL in Japanese patients was smaller than that in Caucasian patients. Together, it appears that FE tends to have more segmental mobility than SS in Japanese patients. The reason why lumbar lordosis involved in finding instability during FE was uncertain. Although other pelvic parameters were also evaluated in this study, any statistical difference could not be found. The shearing stress of disc might be different according to lumbar lordosis. However, it was uncertain and further biomechanical study was needed.

In this study, the differences in the slippage between the PI-FE and PI-SS groups were investigated. The slippage in the flexion of the PI-FE group was greater than that of the PI-SS group, and the slippage in the supine position of the PI-SS group was less than that of the PI-FE group. Moreover, there were no statistically significant differences in the amount of change of LL in flexion. These results indicate that the PI-FE group consisted of patients who tended to increase their slippage by flexion, while the PI-SS group consisted of patients who tended to decrease their slippage in the supine position. Although the pathology that led to these differences was not known, the results from this study suggest that the slippage of all positions (flexion, extension, standing, and supine) should be evaluated to diagnose pathological instability.

Currently, many reports about factors associated with lumbar segmental mobility were described (11-15). Some factors, such as sex, disc degeneration, and facet osteoarthritis, have also been reported. However, the optimal evaluation method conforming to the pathology of segmental mobility remains unclear. In this study, only four patients (12.9%) were diagnosed with pathological instability in both FE and SS. It appears that the segmental mobility revealed in FE is different from that in SS. Further research is required to verify the factors associated with the difference in segmental mobility in FE and SS.

There are some limitations to this study. The sample size was relatively small, and every radiograph was taken only once. Moreover, symptoms, such as low back pain were not evaluated. Percy *et al*. (7) reported that low back pain prevents patients from flexing the lumbar sufficiently.

CONCLUSION

In conclusion, our study showed that both absolute and relative values of ST in FE were greater than those in SS. A reason the results of this study differ from those of previous studies could be the difference in the racial background of the patients. Since the position that revealed the slippage was different for each patient, the slippage of all positions (flexion, extension, standing, and supine) should be evaluated to diagnose pathological instability. Further research is required to verify the factors associated with the difference in segmental mobility in FE and SS.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare that is relevant to the content of this article.

REFERENCES

1. Luk KD, Chow DH, Holmes A : Vertical instability in spondylolisthesis : a traction radiographic assessment technique and the principle of management. Spine (Phila Pa 1976) 28 : 819-827, 2003
2. Wood KB, Popp CA, Transfeldt EE, Geissele AE : Radiographic evaluation of instability in spondylolisthesis. Spine (Phila Pa 1976) 19 : 1697-1703, 1994

3. Cabraja M, Mohamed E, Koeppen D, Kroppenstedt S : The analysis of segmental mobility with different lumbar radiographs in symptomatic patients with a spondylolisthesis. Eur Spine J 21 : 256-261, 2012
4. Liu N, Wood KB, Schwab JH, Cha TD, Pedlow FX Jr, Puhkan RD, Hyzog TL : Utility of Flexion-Extension Radiographs in Lumbar Spondylolisthesis : A Prospective Study. Spine (Phila Pa 1976) 40 : E929-935, 2015
5. Wiltse LL, Hutchinson RH : Surgical treatment of spondylolisthesis. Clin Orthop Relat Res 35 : 116-135, 1964
6. Pitkänen MT, Manninen HI, Lindgren KA, Sihvonen TA, Airaksinen O, Soimakallio S : Segmental lumbar spine instability at flexion-extension radiography can be predicted by conventional radiography. Clin Radiol 57 : 632-639, 2002
7. Pearcy M, Portek I, Shepherd J : The effect of low-back pain on lumbar spinal movements measured by three-dimensional X-ray analysis. Spine (Phila Pa 1976) 10 : 150-153, 1985.
8. Dupuis PR, Yong-Hing K, Cassidy JD, Kirkaldy-Willis WH : Radiologic diagnosis of degenerative lumbar spinal instability. Spine (Phila Pa 1976) 10 : 262-276, 1985
9. Tarpada SP, Cho W, Chen F, Amorosa LF : Utility of supine lateral radiographs for assessment of lumbar segmental instability in degenerative lumbar spondylolisthesis. Spine (Phila Pa 1976) 43 : 1275-1280, 2018
10. Le Huec JC, Hasegawa K : Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. Eur Spine J 25 : 3630-3637, 2016
11. Kong MH, Morishita Y, He W, Miyazaki M, Zhang H, Wu G, Hymanson HJ, Wang JC : Lumbar segmental mobility according to the grade of the disc, the facet joint, the muscle, and the ligament pathology by using kinetic magnetic resonance imaging. Spine (Phila Pa 1976) 34 : 2537-2544, 2009
12. Fujiwara A, Lim TH, An HS, Tanaka N, Jeon CH, Andersson GB, Haughton VM : The effect of disc degeneration and facet joint osteoarthritis on the segmental flexibility of the lumbar spine. Spine (Phila Pa 1976) 25 : 3036-3044, 2000
13. Ellingson AM, Shaw MN, Giambini H, An KN : Comparative role of disc degeneration and ligament failure on functional mechanics of the lumbar spine. Comput Methods Biomech Biomed Engin 19 : 1009-1018, 2016
14. Basques BA, Espinoza Orías AA, Shifflett GD, Fice MP, Andersson GB, An HS, Inoue N : The kinematics and spondylosis of the lumbar spine vary depending on the levels of motion segments in individuals with low back pain. Spine (Phila Pa 1976) 42 : E767-774, 2017
15. Keorochana G, Taghavi CE, Tzeng ST, Morishita Y, Yoo JH, Lee KB, Liao JC, Wang JC : Magnetic resonance imaging grading of interspinous ligament degeneration of the lumbar spine and its relation to aging, spinal degeneration, and segmental motion. J Neurosurg Spine 13 : 494-499, 2010