Analysis of Risk Factors for Postoperative Progressive Segment Degeneration at the Decompression and Non-decompression Segments after Minimally Invasive Lumbar Decompression Surgery: A 5-year Follow-up Study

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Abstract:

Introduction: The risk factors for the development of progressive segment degeneration (PSD) after decompression surgery are still unknown. In this study, the risk factors for PSD in patients who undergo decompression surgery for lumbar spinal stenosis with and without coexisting spondylolisthesis and scoliosis were examined, focusing on decompression and non-decompression segments.

Methods: We reviewed the data of patients with >5 years of postoperative follow up. Radiographic PSD was defined as either the development of an anterolisthesis or retrolisthesis of >3 mm or a decrease in disc height of >3 mm during the 5-year follow up. On the basis of intervertebral segments, the association between PSD and other preoperative clinical findings was analyzed.

Results: Overall, 840 lumbar segments (L1-L2 to L5-S1) in 168 patients, with a mean age of 69.5±9.2 years, met the inclusion criteria. PSD was observed in 162 (19.3%) lumbar segments. A logistic regression model identified that Cobb angle ≥10° (OR 2.53, 95% CI 1.50-4.24), spondylolisthesis ≥3 mm (OR 4.447, 95% CI 2.06-9.58), and level of segments were more likely to have PSD at the non-decompression level; additionally, lateral listhesis ≥3 mm (OR 2.91, 95% CI 1.08-7.81) was more likely to have PSD in the decompression segments. In clinical outcomes in patients with PSD at baseline and the 5-year follow-up, no significant difference was found.

Conclusions: Even though PSD does not correlate with worsening symptoms, our study confirms that a higher degree of pre-existing disc degeneration is indicative of a higher PSD in 5 years.

Keywords:

Lumbar spinal stenosis, Minimally invasive lumbar decompression surgery, Progressive segment degeneration, Adjacent segment disease, 5-year follow-up study

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Introduction

The development of adjacent segment degeneration (ASD) is regarded as a potential complication of spinal fusion. In this study, we reported that progressive segment degeneration (PSD) was observed not only in the decompression segment but also in the adjacent segment (the non-decompression segment) after minimally invasive decompression surgery. As suggested by our results, radiological ASD can occur not only after fusion but also after decompression[1)].

The risk factors for ASD, the major cause of revision surgical procedures after lumbar fusion, have been investigated by several reviews[2-5)]. By contrast, the risk factors for the development of PSD after decompression surgery are still unknown, and we speculated that various factors, including fu-

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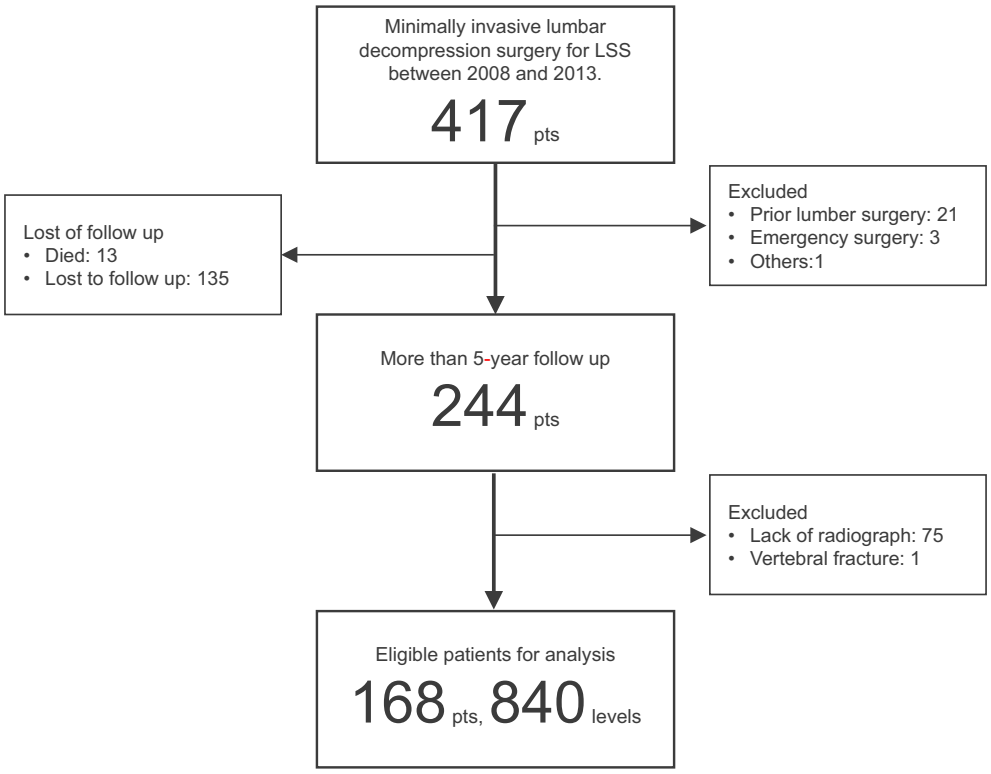

Figure 1. The flow diagram of the study. This study included 168 of 417 patients screened for inclusion.

sion surgery, might be associated with PSD. Additionally, the risk factors may differ between the decompression and non-decompression segments. Therefore, using 5-year follow-up data, the present study aimed to explore the incidence and characteristics of PSD at the decompression or non-decompression segments after decompression surgery.

Materials and Methods

Patient population

We carried out a retrospective analysis of prospectively collected data from patients who underwent minimally invasive lumbar decompression surgery for lumbar spinal stenosis (LSS). Informed consent was obtained from all participants, and the Institutional Review Board of our institution approved the study protocol. The authors of this study received no funding. Fig. 1 shows the flow diagram of the study. We reviewed the data of 244 patients who underwent >5 years of postoperative follow-up. Patients with any missing 5-year follow-up data, such as full-length standing whole-spine radiographs (n=75), and those with a vertebral fracture (n=1) were excluded. As a result, in the study, complete and sufficient demographic, radiographic, and clinical data were available for 168 patients.

Surgical indication and procedure

The surgical indications encompassed instances of leg pain, leg numbness, or a combination of both, resulting in intermittent claudication (rather than back pain). These symptoms were primarily due to spinal canal stenosis, with or without concurrent spondylolisthesis and scoliosis. Our institution's criteria for performing additional fusion procedures included cases of degenerative spondylolisthesis (DS) exhibiting more than 3 mm of translation on dynamic flexion-extension radiography or a posterior opening disc angle exceeding 5° on flexion radiography. Degenerative lumbar scoliosis that is qualified for intervention when characterized by lateral listhesis surpassing 3 mm on standing radiography and a discrepancy in lateral segmental wedging exceeding 3° between standing and prone radiography are also included. Nevertheless, patients who desired minimally invasive decompression surgery or those with comorbidities underwent decompression alone, even when the criteria for additional fusion were satisfied. The patient population of the present study involved LSS with and without coexisting spondylolisthesis and scoliosis who underwent minimally invasive lumbar decompression surgery alone.

All minimally invasive lumbar decompression procedures involved bilateral decompression via a unilateral approach, which targeted the central and bilateral lateral recesses utilizing a microscopic or microendoscopic discectomy system (METRx Medtronic Sofamor Danek, Warsaw, IN, USA), as previously described[6,7].

Definition of PSD

We assessed intervertebral disc height (measured between the midpoints of the upper and lower endplates in millime-

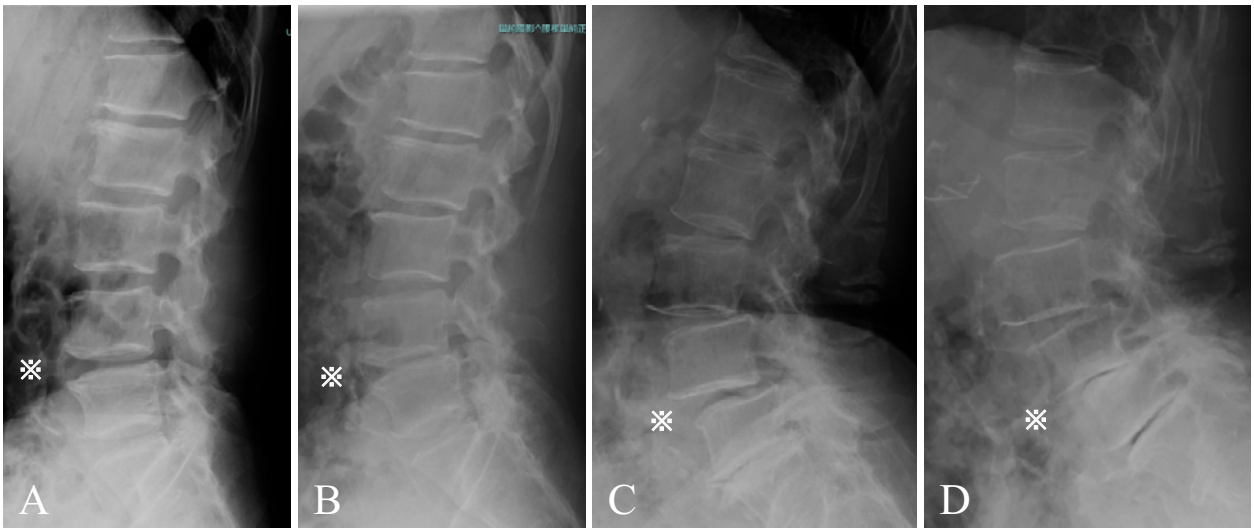

Figure 2. Representative radiographic changes of PSD after L4–L5 single-level decompression. Panels A and C are before surgery, whereas panels B and D are 5 years after surgery. A reduction of more than 3 mm in disc height at the decompression segment is illustrated in the case of A and B. Both A reduction of more than 3 mm in disc height and the development of an anterolisthesis of >3 mm at the decompression segment were observed in the cases of C and D.

ters) and the degree of slip distance (calculated between the posterior-lower portion of the upper vertebral body and the posterior border of the lower vertebral body in millimeters) at levels L1-L2 to L5-S1. Using a standardized method and full-length standing whole-spine radiographs, this evaluation was performed both preoperatively and at the 5-year follow-up[1,8]. Images were independently assessed by two spine surgeons (K.Y. and H.H.) with more than 10 years of experience in spinal surgery; the surgeons were blinded to the study outcomes.

As shown in Fig. 2, the occurrence of either anterolisthesis or retrolisthesis exceeding 3 mm or a reduction of more than 3 mm in disc height during the 5-year follow-up characterizes the radiographic PSD (Fig. 2)[4,9]. All intervertebral discs were divided into two groups depending on whether decompression surgery was performed (decompression and non-decompression levels) in order to evaluate the impact of decompression surgery.

Clinical evaluation

The Japanese Orthopaedic Association (JOA) score for low back pain (ranging from 0=worst to 29=best) was appraised both preoperatively and at the 5-year follow-up. Using the formula, (postoperative JOA score−preoperative JOA score)/(29−preoperative JOA score)×100, the JOA score improvement ratio (%) was computed. Moreover, the patient-oriented questionnaires included an assessment of the visual analog scale (VAS) for leg pain, leg numbness, and back pain (ranging from 0 mm=no pain or numbness to 100 mm= worst imaginable pain or numbness). Reoperation was characterized as lumbar revision surgery conducted because of the postoperative instability or progression of lumbar degeneration, irrespective of the same decompression level or other levels.

Preoperative patient data

The following baseline data were collected: age, sex, body mass index (BMI), smoking status, comorbidities, American Society of Anesthesiologists (ASA) physical status classification system, microendoscopy, and number of decompression segments.

The radiographic spinopelvic parameters, namely, cervical lordosis, thoracic kyphosis, lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), PI-LL, sagittal vertical axis in the sagittal view, and Cobb angle in the coronal view, were measured. Moreover, spondylolisthesis ≥3 mm, lateral listhesis ≥3 mm, and lateral wedging ≥3° at any lumbar level (L1-L2 to L5-S1) were examined using previously recommended methods[10]. On the middle images from the L1-L2 to L5-S1 in the axial plane on preoperative CT, using previously reported methods, axial intervertebral rotation ≥3° and facet joint opening ≥2 mm were evaluated[11,12]. On the ipsilateral (approach) and contralateral sides, using the formula, (postoperative width of the facet/preoperative width of the facet)×100, facet joint preservation ratio was measured[13]. Modic-type changes (types 1-3) and Pfirrmann disc degeneration grades (grades 1-5) from L1-L2 to L5-S1 were evaluated on magnetic resonance imaging (MRI) based on conventional methods[14,15]. We defined facet joint effusion as the presence of either unilateral or bilateral high-intensity signal within the facet joint that closely matched that of the cerebrospinal fluid on axial T2-weighted MRI and examined it from L1-L2 to L5-S1[12].

Statistical analysis

Continuous variables showing a normal distribution were expressed as means±standard deviation. Classification variables underwent conversion into dichotomous variables and were shown as frequencies and percentages. Using the chi-

Table 1. Univariate Risk Analysis of Progressive Segment Degeneration 5 Years on Demographic Variables after Minimally Invasive Lumbar Decompression Surgery.

Variables	Risk factors for PSD (N=840)					Risk factors for PSD in the non-decompression segment (N=605)					Risk factors for PSD in the decompression segment (N=235)				
	PSD yes		PSD no		P-value	PSD yes		PSD no		P-value	PSD yes		PSD no		P-value
Number of intervertebral discs	162	(19.3%)	678	(80.7%)		86	(14.2%)	519	(85.8%)		76	(32.3%)	159	(67.7%)	
Decompression, yes	76	(46.9%)	159	(23.5%)	<0.001										
Age, years	70.6	(8.9)	69.3	(9.3)	0.789	71.1	(8.8)	69.2	(9.2)	0.472	70.0	(9)	69.4	(9.4)	0.750
Male sex	88	(54.3%)	347	(0.4%)	0.485	45	(52.3%)	264	(50.9%)	0.817	43	(56.6%)	83	(52.2%)	0.577
BMI	24.2	(3.4)	24.2	(3.6)	0.442	24.2	(3.3)	24.2	(3.7)	0.426	24.2	(3.6)	24.1	(3.5)	0.934
ASA class															
I	25	(15.4%)	115	(17%)	0.436	16	(18.6%)	88	(17%)	0.829	9	(11.8%)	29	(18.2%)	0.096
II	131	(80.9%)	549	(81%)		67	(77.9%)	420	(80.9%)		64	(84.2%)	129	(81.1%)	
III	6	(3.7%)	14	(2.1%)		3	(3.5%)	13	(2.5%)		3	(3.9%)	1	(0.6%)	
Level of decompression															
1/2	6	(3.7%)	162	(23.9%)	<0.001	6	(7%)	161	(31%)	<0.001	0	(0%)	1	(0.6%)	0.014
2/3	22	(13.6%)	146	(21.5%)		22	(25.6%)	133	(25.6%)		0	(0%)	13	(8.2%)	
3/4	48	(29.6%)	120	(17.7%)		29	(33.7%)	76	(14.6%)		19	(25%)	44	(27.7%)	
4/5	65	(40.1%)	103	(15.2%)		11	(12.8%)	19	(3.7%)		54	(71.1%)	84	(52.8%)	
5/S	21	(13%)	147	(21.7%)		18	(20.9%)	130	(25%)		3	(3.9%)	17	(10.7%)	

Values are shown as numbers, numbers (percent), or medians (interquartile range).

ASA, American Society of Anesthesiologists; BMI, body mass index; PSD, progressive segment degeneration

square test and Mann-Whitney U test, respectively, disparities in categorical and continuous variables were assessed. To identify potential risk factors for revision surgery, multiple logistic regression analysis was conducted on variables with a significance level of P<0.05 in univariate analysis. Odds ratios along with 95% confidence intervals were calculated in this process. Analyses were conducted using SPSS software (version 25.0; SPSS, Chicago, IL, USA).

Results

Patient demographics

The average age and BMI of patients were 69.5±9.2 years and 24.2±3.6 kg/m^2, respectively. Preoperative mean VAS scores for leg pain, leg numbness, and LBP were 62.9±28.0, 61.3±27.9, and 48.1±31.3, respectively, with a JOA score of 13.4±4.5. At the 5-year postoperative follow-up, VAS scores for leg pain, leg numbness, and LBP showed improvement to 31.3±29.3, 17.9±25.8, and 24.4±26.9 respectively, whereas the JOA score increased to 24.1±4.4. The rate of improvement in the JOA score was 67.8%±27.3%.

Prevalence and characteristics of PSD

Table 1, 2 show the differences in characteristics between patients with and without PSD (Some data are omitted due to space limitations). PSD was observed at 162 of 840 (19.3%) levels. Additionally, PSD was observed more frequently in decompression segments than in non-decompression segments (46.9% vs. 23.5%, P<0.001). No differences were found in sex, BMI, smoking status, comorbidity, ASA class, number of decompression levels, and modic-type change in univariate analysis. Regardless of decompression surgery, the following factors were identified as risk factors for PSD after decompression in univariate analysis: surgery (decompression) (P<0.001), level of decompression (P<0.001), Cobb angle ≥10° (44.3% vs. 33.6%, P= 0.011), spondylolisthesis ≥3 mm (23.5% vs. 8.7%, P<0.001), lateral listhesis ≥3 mm (1.5% vs. 1.2%, P=0.004), facet joint opening ≥2 mm (31.5% vs. 21.5%, P<0.001), facet joint effusion (31.5% vs. 15.0%, P<0.001), and Pfirrmann grade (P =0.026).

Risk factors for PSD in the non-decompression segments

The incidence of PSD in non-decompression segments was 86 (14.2%) among the 605 segments. In univariate analysis, PSD in the non-decompression segments was more commonly observed at L3/4 and L4/5 (P<0.001), Cobb angle ≥10° (52.3% vs. 32.8%, P<0.001), spondylolisthesis ≥3 mm (20.9% vs. 3.5%, P<0.001), axial intervertebral rotation ≥3° (2.3% vs. 1.8%, P<0.001), and facet joint effusion (30.2% vs. 11.4%, P<0.001) (Table 1, 2). In multilevel analysis, Cobb angle ≥10° (OR 2.53, 95% CI 1.50-4.24), spondylolisthesis ≥3 mm (OR 4.447, 95% CI 2.06-9.58), L3/4 (OR 9.38, 95% CI 3.572-24.63), L4/5 (OR 9.84, 95% CI 3.002-32.29), and L5/S (OR 3.462, 95% CI 1.321-9.073) were independently associated with the occurrence of PSD in non-decompression segments (Table 3).

Table 2. Univariate Risk Analysis of Progressive Segment Degeneration 5 Years on Radiological Findings after Minimally Invasive Lumbar Decompression Surgery.

Variables	Risk factors for PSD (N=840)					Risk factors for PSD in the non-decompression segment (N=605)					Risk factors for PSD in the decompression segment (N=235)				
	PSD yes		PSD no		P-value	PSD yes		PSD no		P-value	PSD yes		PSD no		P-value
Lumbar lordosis (LL), °, median	31.9	(15)	32.6	(14.3)	0.182	31.2	(15.4)	33.0	(14.2)	0.272	32.7	(14.7)	31.4	(14.3)	0.437
Sacral slope, °, median	26.6	(8.9)	26.9	(8.7)	0.189	25.8	(8.2)	27.2	(8.7)	0.851	27.4	(9.6)	26.1	(8.6)	0.041
Pelvic tilt, °, median	23.7	(10.1)	22.4	(9.9)	0.889	24.1	(10.4)	22.5	(9.7)	0.549	23.4	(9.8)	22.3	(10.4)	0.452
Pelvic incidence (PI), °, median	50.0	(11.6)	49.1	(11.7)	0.982	49.4	(11.8)	49.5	(11.6)	0.881	50.6	(11.4)	48.0	(11.9)	0.954
PI-LL, °, median	18.2	(14.4)	16.5	(15)	0.268	18.3	(15)	16.5	(14.7)	0.953	18.0	(13.7)	16.7	(15.9)	0.056
Sagittal vertical axis (SVA), mm, median	57.7	(38.6)	50.5	(37.2)	0.503	57.2	(42.3)	50.7	(37.1)	0.263	58.4	(34)	50.2	(37.9)	0.863
SVA ≥50 mm, n (%)	79	(48.8%)	336	(49.6%)	0.862	43	(50%)	261	(50.3%)	1.000	36	(47.4%)	75	(47.2%)	1.000
Scoliosis, Cobb degree, °, median	7.8	(9.5)	6.2	(9.0)	0.043	9.0	(9.5)	6.0	(9.0)	0.514	6.5	(9.3)	6.7	(9.1)	0.366
Scoliosis, Cobb ≥10°, n (%)	72	(44.4%)	228	(33.6%)	0.011	45	(52.3%)	170	(32.8%)	<0.001	27	(35.5%)	58	(36.5%)	1.000
Spondylolisthesis, ≥3 mm, n (%)	38	(23.5%)	59	(8.7%)	<0.001	18	(20.9%)	18	(3.5%)	<0.001	20	(26.3%)	41	(25.8%)	0.525
Lateral listhesis, ≥3 mm, n (%)	17	(10.5%)	30	(4.4%)	0.004	6	(7%)	20	(3.9%)	0.150	11	(14.5%)	10	(6.3%)	0.038
Lateral wedging angle, °, median	1.8	(2.7)	1.4	(2.2)	0.020	2.1	(2.9)	1.3	(2.1)	0.167	1.4	(2.3)	1.6	(2.6)	0.167
Lateral wedging, ≥3°, n (%)	40	(24.7%)	154	(22.7%)	0.604	26	(30.2%)	113	(21.8%)	0.097	14	(18.4%)	41	(25.8%)	0.250
CT findings															
Axial intervertebral rotation, ≥3°, n (%)	30	(18.5%)	89	(13.1%)	0.080	19	(22.1%)	62	(11.9%)	0.016	11	(14.5%)	27	(17%)	0.707
Facet joint opening, n (%)	51	(31.5%)	146	(21.5%)	0.010	23	(26.7%)	94	(18.1%)	0.076	28	(36.8%)	52	(32.7%)	0.558
Facet preservation ratio (ipsilateral), median											94.3	(9.7)	94.0	(10.4)	0.827
Facet preservation ratio (contralateral), median											96	(8.1)	96.5	(9.6)	0.665
MRI findings															
Facet joint effusion, n (%)	51	(31.5%)	102	(15%)	<0.001	26	(30.2%)	59	(11.4%)	<0.001	25	(32.9%)	43	(27%)	0.442
Pfirrmann grade, median															
1	0	(0%)	0	(0%)	0.026	0	(0%)	0	(0%)	0.139	0	(0%)	0	(0%)	0.462
2	0	(0%)	8	(1.2%)		0	(0%)	7	(1.3%)		0	(0%)	1	(0.6%)	
3	19	(11.7%)	141	(20.8%)		11	(12.8%)	115	(22.2%)		8	(10.5%)	26	(16.4%)	
4	130	(80.2%)	480	(70.8%)		67	(77.9%)	363	(69.9%)		63	(82.9%)	117	(73.6%)	
5	12	(7.4%)	45	(6.6%)		7	(8.1%)	31	(6%)		5	(6.6%)	14	(8.8%)	

Values are shown as numbers, numbers (percent), or medians (interquartile range).

CT, computed tomography; MRI, magnetic resonance imaging; PSD, progressive segment degeneration

Risk factors for PSD in the decompression segments

The incidence of PSD in decompression segments was 76 (32.3%) among the 235 segments. In univariate analysis, PSD in the decompression segments was more commonly observed at L4/5 (P<0.001) (Table 2). Compared with those in the PSD (−) group, SS (27.4° vs. 26.1°, P=0.041), length of lateral listhesis (0.6 mm vs. 0.3 mm, P=0.010), and axial inter-rotation angle (1.6° vs. 1.1°, P=0.001) in the PSD (+) group were significantly larger. Multilevel analysis showed that lateral listhesis ≥3 mm (OR 2.91, 95% CI 1.08-7.81) was independently associated with the occurrence of PSD in decompression segments (Table 3).

Clinical outcomes in patients with PSD

At the 5-year follow-up, PSD was observed in 63.1% (106/168) of patients and 43.5% (73/168) of patients at the decompression segment. Table 4 shows the changes in VAS

Table 3. Multivariate Risk Analysis of PSD 5 Years after Minimally Invasive Lumbar Decompression Surgery.

Variables	Risk factors for PSD in the non-decompression segment (N=605)			Risk factors for PSD in the decompression segment (N=235)		
	Adjusted odds ratio	95% CI	P-value	Adjusted odds ratio	95% CI	P-value
Age, years	1.018	0.988–1.049	0.250	1.009	0.977–1.041	0.603
Male sex	0.441	0.489–1.366	0.817	0.772	0.430–1.386	0.386
Scoliosis, Cobb ≥10°	2.525	1.504–4.239	<0.001	0.749	0.398–1.406	0.368
Spondylolisthesis ≥3 mm	4.447	2.064–9.584	<0.001	1.042	0.544–1.995	0.902
Lateral listhesis ≥3 mm,	0.704	1.957–1.995	0.253	2.906	1.081–7.812	0.034
Facet joint opening ≥2 mm	1.086	1.962–1.988	0.601	1.129	0.625–2.040	0.687
Level						
L1/2	(Ref)			-	-	-
L2/3	4.001	1.543–10.374	0.004	-	-	-
L3/4	9.380	3.572–24.632	<0.001	-	-	-
L4/5	9.846	3.002–32.291	<0.001	-	-	-
L5/S	3.462	1.321–9.073	0.012	-	-	-

PSD, progressive segment degeneration

Table 4. Comparison of Clinical Outcomes between Patients with and Those without Progressive Segment Degeneration at the Decompression or Adjacent Segments.

	PSD at all segments		P-value	PSD at decompression segments		P-value
	Yes	No		Yes	No	
Number of patients	106	62		73	95	
Preoperative						
VAS LBP	50.0±30.9	45.2±32.0	0.357	46.3±30.9	49.4±31.7	0.532
VAS leg pain	62.3±28.5	63.9±27.5	0.737	58.1±29.8	65.9±26.4	0.112
VAS leg numbness	59.8±27.3	63.7±28.9	0.405	60.0±28.4	62.2±27.6	0.614
JOA score	13.2±4.5	13.8±4.5	0.334	13.6±4.5	13.3±4.4	0.688
5-year follow-up						
VAS LBP	26.4±27.5	20.9±25.7	0.122	25.2±28.1	23.7±26.0	0.744
VAS leg pain	20.2±26.4	13.6±24.2	0.070	20.9±27.1	15.3±24.4	0.204
VAS leg numbness	33.2±29.8	27.6±28.2	0.138	29.8±28.1	32.6±30.4	0.588
JOA score	24.0±4.5	24.2±4.3	0.380	24.5±4.6	23.8±4.3	0.402
JOA score improvement ratio	68.6±26.1	66.5±29.7	0.338	70.4±27.3	65.7±27.4	0.317
Reoperation						
Same level	3 (2.8)	5 (8.1)	0.124	2 (2.7)	6 (6.3)	0.281
Another level	8 (7.5)	4 (6.5)	0.527	4 (5.5)	8 (8.4)	0.453
Total	11 (10.4)	9 (14.5)	0.287	6 (8.2)	14 (14.7)	0.196

Values are shown as number, number (percent), or median (interquartile range).

LBP, low back pain; JOA, Japanese Orthopaedic Association; PSD, progressive segment degeneration; VAS, visual analog scale

(leg pain, leg numbness, and LPB) and JOA scores according to PSD at all segments and decompression segments only. There was no significant difference in clinical outcomes at baseline and the 5-year follow-up between patients with PSD at all segments and decompression segments. Nevertheless, patients with PSD had poorer VAS scores for leg pain, leg numbness, and LBP at 5 years than those without PSD, although the differences were not significant.

A total of 20 patients underwent revision surgery, of which eight surgeries (4.8%) were performed at the same level and 12 (7.1%) at other levels. There was no significant difference in the occurrence of revision surgery between patients with and without PSD in all segments or decompression segments.

Discussion

Several studies have investigated the risk factors for symptomatic ASD after fusion surgery; however, the risk factors for PSD-like ASD after decompression surgery re-

main unknown. Our 5-year follow-up study showed that surgery (decompression), Cobb angle ≥10°, spondylolisthesis ≥3 mm, lateral listhesis ≥3 mm, facet joint opening ≥2 mm, lumbar level, and Pfirrmann grade were significantly associated with radiological PSD. Surgery and a higher degree of pre-existing disc degeneration foreshadow a higher PSD in 5 years.

Generally, spine surgeons pay attention to factors that increase the risk of reoperations at the index level after decompression alone and risk factors for adjacent segment disease after fusion surgery. The National Swedish Spine Register (Swespine) reported that the reoperation rate of LSS without DS was 6.2% at the index level and 7.0% at the other levels after decompression surgery. The reoperation rate for LSS with DS was 6.0% at the index level and 7.4% at other levels after decompression surgery. The reoperation rate for LSS without DS after fusion surgery was 5.6% at the index level and 10.6% at other levels. The reoperation rate for LSS with DS after fusion surgery was 3.8% at the index level and 13.1% at the other levels[16]. Recent studies showed that the rate of reoperation at the index level and that at the adjacent level after decompression surgery were comparable[16,17]. PSD, ASD, and recurrent stenosis in the lumbar spine cause low back pain and can also be a factor in reoperation[18-20]. Therefore, after minimally invasive decompression surgery using 5-year followup data, risk factors for PSD must be investigated at the decompression and non-decompression segments.

One prominent finding of the present study was that PSD was observed in 46.9% of decompression segments and 23.5% of non-decompression segments at the 5-year follow-up. Similarly, Ravinsky et al. reported that the spondylolisthesis slip percentage increased in 55.4% of patients with grade I-II DS at the 1.7-year follow-up after midline-sparing decompression[21]. Minimally invasive surgery using a microscope or an endoscope has further reduced the risk of iatrogenic instability while obviating the need for fusion[6,22]. Many lumbar lesions requiring surgery are assumed to be coexisting with severe disc degeneration and PSD at the decompression segment might be due to the natural course. Surgeons should take care of biomechanical changes after decompression surgery does not accelerate lumbar segmental degeneration.

Our multivariate analysis stratified by decompression procedure demonstrated that the level of the segment (L3/4 and L4/5), spondylolisthesis ≥3 mm, and lateral listhesis ≥3 mm were associated with PSD in the non-decompression segment and lateral listhesis ≥3 mm was associated with PSD in decompression segments. Similar to our findings, Fujii et al. carried out a prospective longitudinal MRI study for patients with LSS after decompression surgery and reported that progression of decrease in signal intensity and posterior disk protrusion occurs commonly at the upper level of the lumbar spine and disk space narrowing at the lower level[23]. Using a 15-year community-based cohort study, Enyo Y et al. explored the radiographic natural course of DS and found that lumbar axis sacral distance, facet sagittalization, and the existence of slip at baseline were risk factors for L4 slip progression[24]. Vertebral rotation in combination with lateral listhesis or independently is believed to be moderately associated with the progression of spinal deformity[25]. Segmental instability, such as anterior or lateral listhesis, is caused primarily by facet dysfunction, which in turn may accelerate disc degeneration. In this regard, we surmise that these risk factors are partially similar to the radiographic risk factors for ASD after fusion surgery. High BMI, facet joint violation, anterior shift of the preoperative and postoperative lumbosacral sagittal plumb line, decreased preoperative and postoperative LL, preoperative adjacent disc degeneration, decreased preoperative adjacent disc height, increased postoperative lumbopelvic mismatch, postoperative pelvic incidence, and postoperative PT were significantly related to ASD, as revealed by recent meta-analysis of ASD after lumbar fusion surgery[5]. Yokoyama et al. reported that 39/95 patients developed symptomatic ASD after standard decompression surgery during a mean 7.5-year follow-up; additionally, the study reported preoperative larger axial intervertebral rotation angle of adjacent segments are risk factors for ASD[26]. The authors speculated that the decreased range of motion of the operated level stressed the adjacent segment and caused ASD after decompression surgery. Even though most postoperative degenerative changes after decompression surgery were related to radiological PSD[1,21], PSD, ASD, and recurrent stenosis in the lumbar spine may cause reoperation. Notably, the degree of preoperative disc degeneration, such as lateral listhesis ≥3 mm, is more important than alignment in the development of PSD after decompression surgery.

This study has some limitations. First, because of the retrospective nature of the study, selection bias was unavoidable, and all possible risk factors for radiological ASD in the analysis could not be included. Second, the number of patients at the operated and non-operated disc levels was not equally distributed. Third, we limited the study participants to patients who could undergo postoperative follow-up for at least 5 years. From this study, patients with incomplete postoperative data were excluded. Future prospective research should investigate the causal relationships between various risk factors and PSD and evaluate the effects of modifying these factors on subsequent PSD development.

To conclude, PSD occurred in 19.3% of the 840 spinal levels analyzed, and it was more common in decompression segments than in non-decompression segments. Although PSD does not correlate with worsening symptoms, our study confirms that a higher degree of pre-existing disc degeneration may lead to a higher PSD.

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