Original Article Clinics in Orthopedic Surgery 2023;15:800-808 • https://doi.org/10.4055/cios22362

Midterm Outcomes of Muscle-Preserving Posterior Lumbar Decompression via Sagittal Splitting of the Spinous Process: Minimum 5-Year Follow-up

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Background: To overcome several disadvantages of conventional laminectomy for degenerative lumbar spinal stenosis (DLSS), several types of minimally invasive surgery have been developed. The purpose of the present study was to report the clinical and radiological mid-term outcomes of spinous process-splitting decompression (SPSD) for DLSS.

Methods: Seventy-three consecutive patients underwent SPSD between September 2014 and March 2016. Of these, 42 (70 segments) who had at least 5 years of follow-up were analyzed retrospectively. The visual analog scale for back pain and leg pain, Oswestry disability index, and walking distance without resting were scored to assess clinical outcomes at the preoperative and final follow-up. A subgroup analysis was performed according to the union status of the split spinous processes (SPs). For radiological outcomes, slip in the neutral position as a static parameter, anterior flexion-neutral translation, and posterior extension-neutral translation as a dynamic parameter were measured before and at the final follow-up after surgery. Spinopelvic parameters were also measured. Reoperation rate at the index levels was investigated, and predictive risk factors for reoperation were evaluated using multivariate logistic regression. Survival analysis was performed with reoperation as the endpoint to estimate the longevity of the SPSD for DLSS.

Results: All clinical outcomes improved significantly at the final follow-up compared to those at the initial visit ($p < 0.05$). The clinical outcomes did not differ according to the union status of the split SP. There were no cases of definite segmental instability and no significant changes in the static or dynamic parameters after surgery. Sacral slope and lumbar lordosis increased, and pelvic tilt decreased significantly at the follow-up ($p < 0.05$), despite no significant change in the sagittal vertical axis. The mean longevity of the procedure before the reoperation was 82.9 months. Five patients (11.9%) underwent reoperation at a mean of 52.2 months after the SPSD. There were no significant risk factors for reoperation; however, the preoperative severity of foraminal stenosis had an odds ratio of 7.556 ($p = 0.064$).

Conclusions: SPSD for DLSS showed favorable clinical and radiological outcomes at the mid-term follow-up. SPSD could be a good surgical option for treating DLSS.

Keywords: *Spinal stenosis, Spinous process splitting, Decompression, Mid-term outcomes*

Received November 17, 2022; Revised March 3, 2023; Accepted March 3, 2023

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Clinics in Orthopedic Surgery • pISSN 2005-291X eISSN 2005-4408

Posterior decompression is a highly effective surgical technique for symptomatic degenerative lumbar spinal stenosis (DLSS), which does not improve with conservative treatment.[1-3] In the conventional laminectomy technique, the bilateral paraspinal muscles are detached from the spinous process (SP), laminae, and facet joints, and posterior elements including SP, supra- and interspinous ligaments are sacrificed. In this procedure, the paraspinal muscles lose their insertions and are denervated by injury to the medial branch of the dorsal ramus. Thus, it can cause atrophy of the paraspinal muscles, mechanical back pain, and segmental instability. In addition, the rate of revision surgery including fusion is high, especially in cases with degenerative spondylolisthesis.[4-6]

To overcome these disadvantages, several types of minimally invasive surgery (MIS) have been developed, such as spinous process-splitting decompression (SPSD), unilateral laminectomy and bilateral decompression (ULBD), and percutaneous endoscopic decompression (PED).[6-9] Among these MIS techniques, SPSD, first introduced by Watanabe et al.,[7] is a decompression procedure that uses the surgical pathway approached by sagittal splitting of SP, which preserves the muscular attachments to SP.

There have been many favorable clinical outcomes using SPSD modified by other surgeons; however, these are limited to short-term follow-up.[10,11] Furthermore, few studies have reported the possibility of delayed instability, reoperation rate, and effects on the clinical outcomes of union status of the split SP after SPSD. The purpose of the present study was to report the clinical and radiological mid-term outcomes of SPSD for DLSS.

METHODS

Patient Enrollment

The Institutional Review Board of Seoul National University Hospital approved this study (No. H-2202-075-1299). Written consent from patients was waived due to anonymous data collection and the retrospective nature of the study. Seventy-three consecutive patients underwent SPSD for DLSS including grade I degenerative spondylolisthesis between September 2014 and March 2016. Of these, 42 patients (70 segments) who had at least 5 years of follow-up were analyzed retrospectively. Patients with definite lumbar instability (angular motion more than 10° or translational motion more than 4 mm), grade II or greater degenerative spondylolisthesis, congenital, spondylolytic, and iatrogenic stenosis, or a history of surgery of the lumbar spine were excluded.[12)]

Surgical Procedures

The authors' modified SPSD was performed as previously reported.[11] It was based on the technique introduced by Watanabe et al.[7] and modified by Cho et al.,[13] Nomura et al.,[10] and Hatta et al.[14] Under general anesthesia, a posterior midline approach was performed, and the supraspinous and interspinous ligaments were sharply divided using a #10 scalpel blade. The proximal SP at the level to be decompressed was then split vertically and equally into the base using an ultrasonic blade (Fig. 1A). The split SPs were cut at the spinolaminar junction with a curved chisel and retracted to expose the surgical corridor for decompression, leaving an insertion of bilateral paraspinal muscles to SP (Fig 1B). After microscopic decompression (Fig. 1C), the split SPs were approximated and sutured along with the periosteum and supra- and interspinous ligaments (Fig. 1D).

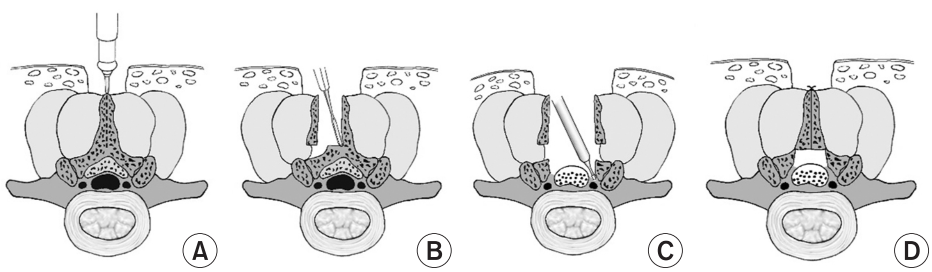

Fig. 1. Schematic demonstration of spinous process-splitting decompression. (A) The spinous process was split vertically and equally into the base using an ultrasonic blade along the dotted line. (B) The split spinous processes were cut from the spinolaminar junction using a curved chisel and retracted to expose a surgical corridor for decompression, leaving an insertion of bilateral paraspinal muscles to the spinous process. (C) The Gelpi retractor was applied to maintain the operation field and the nerve tissues were adequately decompressed using a high-speed burr and Kerrison punch under a microscope. (D) After decompression, the split spinous processes were approximated and sutured along with the periosteum and supra- and interspinous ligaments.

Outcome Measures

For clinical assessment, the visual analog scale for back pain and leg pain, Oswestry disability index, and walking distance without resting were scored before surgery and at the final follow-up. Walking distance without resting refers to the patient's subjective distance where neurogenic intermittent claudication occurs. A subgroup analysis was done according to the union status of the split SP. Bony union was evaluated both between the split SP and at the spinolaminar junction using computed tomography taken 6–18 months after surgery. The union status was classified into the complete union (restoration of spinolaminar junction), partial union (floating union of SP), and nonunion, as previously reported (Fig. 2).[11] The operative time and estimated blood loss were also investigated.

Radiologic outcomes were assessed using simple radiographs, including standing anteroposterior, lateral, and flexion-extension lateral views preoperatively and at the final follow-up. In addition to assessing spinal instability, static parameters were obtained from the anterior or posterior slip in the neutral position. Dynamic parameters included anterior flexion-neutral translation and posterior extension-neutral translation (Fig. 3).[15] All parameters were measured at the operated levels. Spinopelvic parameters including pelvic incidence, pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), and sagittal vertical axis (SVA) were measured using whole-spine lateral radiographs.

The reoperation rate at the index levels and the predictive risk factors for reoperation were investigated. The predictive risk factors included age, sex, body mass index, diabetes mellitus, the severity of central or foraminal stenosis, spondylolisthesis, retrolisthesis, preoperative disc height, static and dynamic parameters at the operated levels, and Pfirrmann grade.[15-19] In the case of central canal stenosis, Schizas grade A was considered as mild, grade B as moderate, and grade C and D as severe.[18] According to the grading system suggested by Lee et al.,[19] foraminal stenosis was classified as normal (none), mild, moderate, and severe. Survival analysis was performed with reoperation as the endpoint to estimate the longevity of the SPSD for DLSS.

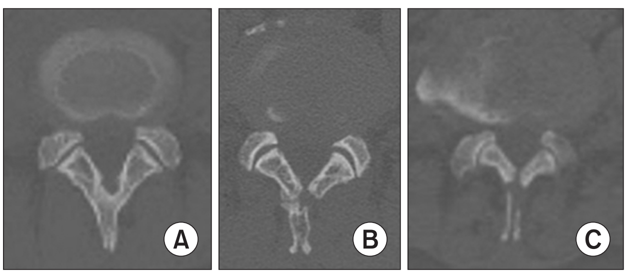

Fig. 2. Union status of the split spinous processes. (A) Complete union (restoration of spinolaminar junction). (B) Partial union (floating union of the spinous process). (C) Nonunion.

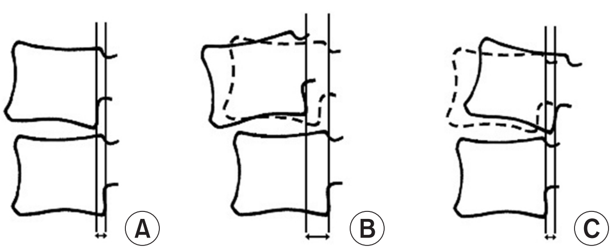

Fig. 3. Static and dynamic parameters. Positive values indicate anterior slip and negative values indicate posterior slip. (A) Slip in the neutral position. (B) Anterior flexion-neutral translation, the slip difference between flexion and neutral positions. (C) Posterior extension-neutral translation, the slip difference between extension and neutral positions.

Statistical Analysis

IBM SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. Student *t*-test or the Mann-Whitney test was carried out for continuous variables, and

Table 1. Demographics and Baseline Characteristics

Characteristics	Value
Age at the time of operation (yr)	67.2 ± 7.2
Sex (male : female)	30 : 12
BMI (kg/m^2)	25.5 ± 3.4
Level of operation	
1	23
2	12
3	5
4	2
Operative time (min)	
Per person	83.9 ± 33.5 (30–180)
Per level	56.7 ± 24.2 (21–133)
EBL (mL)	
Per person	142.9 ± 105.7 (50–500)
Per level	88.0 ± 45.9 (25–250)
Follow-up period (mo)	75.3 ± 5.3 (68–87)
DM	12

Values are presented as mean ± standard deviation (SD) or mean ± SD (range).
BMI: body mass index, EBL: estimated blood loss, DM: diabetes mellitus.

chi-square or Fisher's exact test was carried out for categorical variables. A paired t-test was used to assess clinical and radiological outcomes. Multivariate logistic regression analysis was performed to find out the predictive risk factors. Kaplan-Meier analysis was performed to estimate the longevity of the procedure before the reoperation. A p-value less than 0.05 was considered statistically significant.

RESULTS

Patient demographic variables and baseline characteristics are presented in Table 1. All clinical outcomes improved significantly at the final follow-up compared to those at the initial visit (Table 2). Good results in the short-term follow-up were well maintained in the mid-term follow-up (Fig. 4). Clinical outcomes did not differ according to the union status of the split SP (Table 3). Radiological outcomes were evaluated in 30 patients and 52 segments. There were no cases of definite segmental instability and no significant changes in the static or dynamic parameters after surgery. SS and LL increased, and PT decreased significantly at the final follow-up (Table 4).

The mean longevity of the procedure before the reoperation was 82.9 months (Fig. 5). The rate of good results through the mid-term follow-up was 88.1% (37/42

Table 2. Comparison of Clinical Outcomes

Variable	Preoperative (n = 42)	Final (n = 42)	*p*-value
VAS-BP	4.6 ± 2.2	3.3 ± 2.7	0.031*
VAS-LP	7.7 ± 1.3	3.1 ± 3.3	0.000*
ODI	38.5 ± 6.8	11.2 ± 9.3	0.000*
Walking distance (m)	201.6 ± 273.1	1,391.2 ± 1,142.2	0.000*

Values are presented as mean ± standard deviation.
VAS-BP: visual analog scale for back pain, VAS-LP: visual analog scale for leg pain, ODI: Oswestry disability index.
*Significant difference.

Table 3. Comparison of Clinical Outcomes According to the Degree of Union of the Split Spinous Process

Variable	Complete union (n = 17)	Partial union or nonunion (n = 25)	*p*-value
Final VAS-BP	2.9 ± 2.4	3.6 ± 2.9	0.364
Final VAS-LP	2.9 ± 2.8	3.3 ± 3.6	0.759
Final ODI	10.0 ± 9.2	12.0 ± 9.6	0.511
Final walking distance (m)	1,784.1 ± 1,222.6	1,124.0 ± 1,023.9	0.065

Values are presented as mean ± standard deviation.
VAS-BP: visual analog scale for back pain, VAS-LP: visual analog scale for leg pain, ODI: Oswestry disability index.

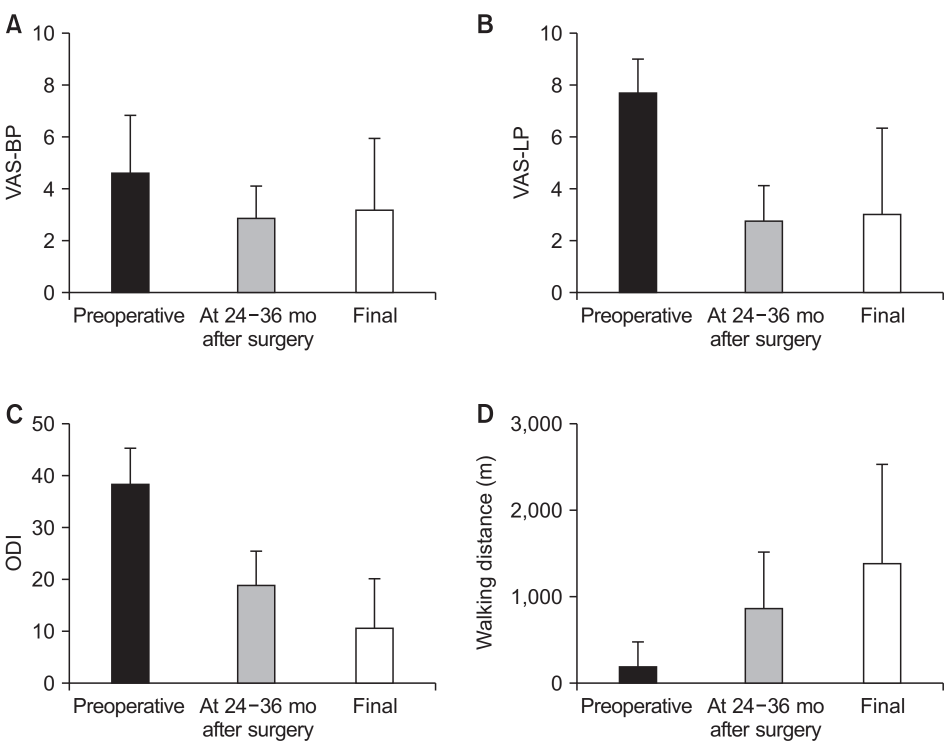

Fig. 4. Clinical outcomes at preoperative, 24–36 months after surgery (short-term follow-up), and final follow-up (mid-term follow-up). (A) Visual analog scale for back pain (VAS-BP). (B) VAS for leg pain (VAS-LP). (C) Oswestry disability index (ODI). (D) Walking distance.

Table 4. Comparison of Radiological Outcomes

Variable	Preoperative (n = 30)	Final (n = 30)	*p*-value
PI	45.3 ± 8.9	45.9 ± 8.6	0.293
PT	18.0 ± 7.9	15.6 ± 8.5	0.014*
SS	27.3 ± 8.4	30.2 ± 7.9	0.003*
LL	39.3 ± 12.1	41.86 ± 12.7	0.038*
PI-LL	6.0 ± 13.9	4.4 ± 14.3	0.244
SVA (mm)	30.2 ± 48.1	32.5 ± 38.2	0.802
Slip in neutral position (mm)†	0.58 ± 3.22	0.93 ± 3.60	0.053
Anterior flexion-neutral translation (mm)†	0.30 ± 0.56	0.30 ± 0.82	0.969
Posterior extension-neutral translation (mm)†	0.33 ± 0.60	0.29 ± 0.61	0.633

Values are presented as mean ± standard deviation.
PI: pelvic incidence, PT: pelvic tilt, SS: sacral slope, LL: lumbar lordosis, SVA: sagittal vertical axis.
*Significant difference. †n = 30 patients and 52 segments.

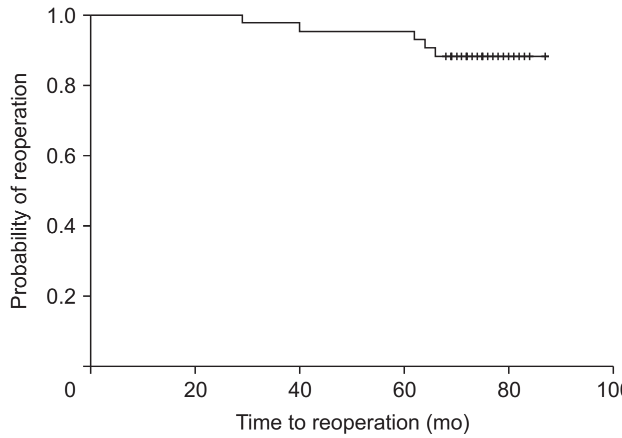

Fig. 5. Longevity of spinous process-splitting decompression before reoperation.

patients) (Fig. 6). The reoperation rate was 11.9% (5/42 patients) (Fig. 7) and 5 patients underwent fusion surgery at a mean of 52.2 months after the initial surgery. The causes of reoperation included 4 cases of foraminal stenosis and 1 case of incorrect level of initial surgery. There were no cases of reoperation because of insufficient decompression. There were no different variables between the patients who underwent reoperation and those who did not (Table 5). There were no significant risk factors for reoperation; however, the preoperative severity of foraminal stenosis had an odds ratio of 7.556 ($p = 0.064$).

DISCUSSION

The outcome was poor in approximately 50% of patients after conventional laminectomy owing to excessive tissue damage and secondary instability.[20,21] Among several MIS techniques used to overcome the limitations of conventional laminectomy, ULBD has the advantage of preserving the contralateral paraspinal muscle, facet joint, and neural arch. However, minor trauma to the paraspinal muscle, poor visualization of the contralateral side, and the possibility of excessive removal of the ipsilateral facet joint are disadvantages of ULBD.[6,22,23] Despite excellent magnification and illumination with a wide view, PED has potential limitations, including difficulty in bleeding control in patients with a bleeding tendency and substantial learning curve.[8,23]

SPSD has several advantages, such as muscle-preserving techniques, few facet joint injuries, symmetrical surgical visualization of the lateral recesses, and flatter learning curve compared to ULBD and PED. Nevertheless, there are concerns about the possibility of the restoration of split SP. This is because complete union of the spinolaminar junction as an insertion of the paraspinal muscles is important for retaining lever function.[7,10,11,13,14]

The authors previously reported that complete union, partial union, and nonunion were observed in 51.7%, 43.2%, and 5.1% of patients, respectively, after SPSD (n = 73). No significant differences were observed in the short-term clinical outcomes according to the union status of the split SP.[11] In a clinical study by Kakiuchi and Fukushima,[24] osseous discontinuity between SP and lamina did not affect the clinical outcomes 2 or 4 years after SP-split open-door laminoplasty. However, osseous continuity was important to maintain the positive surgical benefit at a long-term follow-up of 10 to 12 years. In our study, although the clinical outcomes in the complete union group were better at the mid-term follow-up, there were still no significant differences according to the union status. It is necessary to establish the effects of the union status of the split SP on long-term outcomes following SPSD.

The decompressive procedure can injure the facet joints, especially when undercutting the lateral recess, resulting in instability at the operated levels.[5,25] In this study, there were no cases of delayed instability and no significant changes in static or dynamic parameters at the mid-term follow-up. These results were because the posterior ligament complex, including the facet joint, was less damaged and the paraspinal muscles were preserved when performing SPSD.

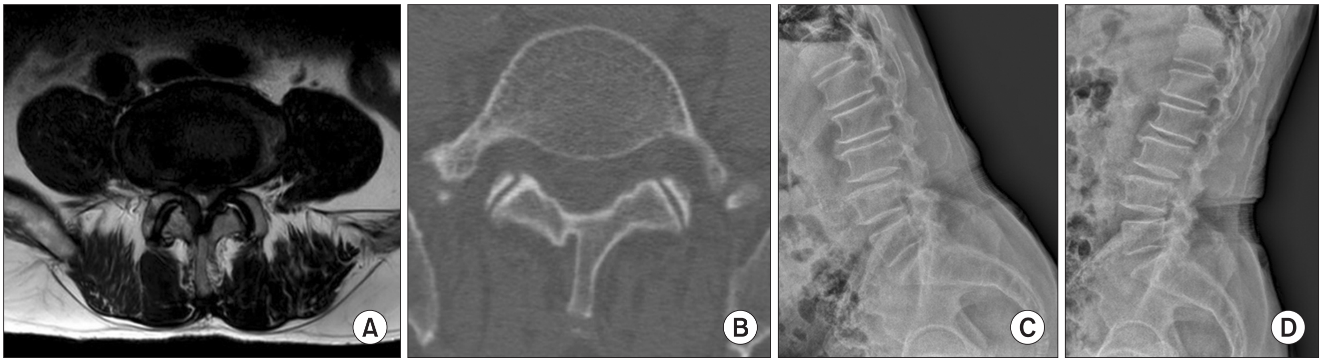

Fig. 6. A 69-year-old male patient diagnosed with degenerative spinal stenosis at the L4–5 level underwent spinous-process splitting decompression (SPSD). (A) The preoperative axial magnetic resonance image revealed severe spinal stenosis. (B) The postoperative computed tomography showed complete union of the split spinous processes and the well-preserved paraspinal muscles after SPSD. Flexion (C) and extension (D) radiographs did not show definite segmental instability at the final follow-up. Good results were obtained not only in the short-term follow-up but also in the mid-term follow-up.

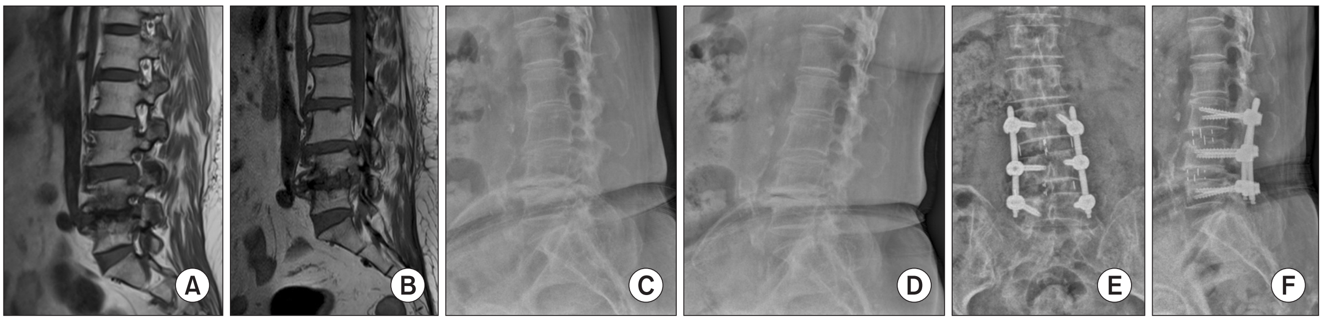

Fig. 7. A 64-year-old female patient underwent spinous-process splitting decompression (SPSD) at the L3–4–5 level. Clinical outcomes were good at the short-term follow-up, but were not maintained at the mid-term follow-up. There was a severe foraminal stenosis on initial (A) and mid-term (B) follow-up axial magnetic resonance imaging. There was no instability on flexion (C) and extension (D) radiographs before revision surgery. Oblique lumbar interbody fusion was performed at 62 months after SPSD. Anteroposterior (E) and lateral (F) radiographs of the lumbar spine at the 1-year follow-up after fusion surgery.

The adaptive stooping posture in patients with DLSS is considered a temporary sagittal imbalance to reduce buckling of the ligamentum flavum. Several studies have reported improvements in sagittal balance and LL after decompression surgery without fusion in short-term follow-up.[26,27] Likewise, SS and LL increased, and PT decreased in this study, despite no significant change in SVA at the mid-term follow-up.

Decompression surgery for DLSS is mainly performed in elderly patients because spinal stenosis is a degenerative disease.[3] The mean longevity of SPSD before reoperation of 82.9 months seems to be significant, considering the life expectancy of elderly patients. Of the 42 patients, 5 underwent revision fusion surgery at a mean of 52.2 months following the initial surgery (11.9%). The reoperation rate was consistent with those reported in previous studies. Scholler et al.[6] reported an overall reoperation rate of 17.0%, and previous lumbar surgery was a predictor of reoperation after ULBD. In a retrospective study by Hwang et al.,[16] 16.3% of patients after ULBD underwent reoperation at the index levels, and moderate disc degeneration (Pfirrmann grade IV) in the lower lumbar segments was determined as a risk factor for reoperation. Other studies found that the causes of reoperation in the first 4 years were inadequate decompression, disease progression, technical errors, and postoperative complications.[17] In our study, there were no cases of reoperation owing to inadequate decompression. We attributed these findings to the symmetrical surgical visualization of the lateral recesses and flatter learning curve, with a visualization similar to that of conventional laminectomy. Although there were no significant predictive factors for reoperation in this study, the preoperative severity of foraminal stenosis had an odds ratio of 7.556 (p = 0.064). Ikegami et al.[15] reported that 15.3% of patients with preoperative asymptomatic foraminal stenosis had revision surgery because of

Table 5. Variables Associated with Reoperation

Variable	No reoperation (n = 37)	Reoperation (n = 5)	*p*-value
Age at the time of operation (yr)	67.4 ± 7.2	66.0 ± 7.9	0.706
Sex (male : female)	26 : 11	4 : 1	1.000
BMI (kg/m^2)	25.4 ± 3.1	26.3 ± 5.3	1.000
DM	9	3	0.131
Central stenosis			0.636
Severe	22	2	
Moderate	15	3	
Foraminal stenosis			0.099
Severe	3	2	
None, mild, or moderate	34	3	
Level of initial operation			0.739
L2–3	7	0	
L3–4	17	1	
L4–5	33	4	
L5–S1	7	1	
Mean level of initial operation	1.7 ± 0.9	1.2 ± 0.4	0.207
Preoperative ADH	12.6 ± 4.0	11.8 ± 7.4	0.472
Preoperative PDH	7.4 ± 2.4	6.9 ± 2.5	0.624
Preoperative segmental angle	7.7 ± 4.4	8.2 ± 8.0	0.706
Preoperative slip in neutral position	0.93 ± 3.12	0.51 ± 1.14	0.940
Preoperative anterior flexion-neutral translation	0.41 ± 0.72	0.26 ± 0.57	0.571
Preoperative posterior extension-neutral translation	0.33 ± 0.61	0.26 ± 0.58	0.624
Pfirrmann grade			0.188
IV	32	3	
V	5	2	

Values are presented as mean ± standard deviation.
BMI: body mass index, DM: diabetes mellitus, ADH: anterior disc height, PDH: posterior disc height.

delayed-onset symptoms of foraminal stenosis at the index level after central decompression. It is supposed that SPSD has limitations in the decompression of foraminal stenosis. Despite statistical insignificance, fusion surgery or endoscopic decompression can be considered in patients with severe foraminal stenosis.[28,29]

There are certain limitations of our study including the retrospective design, the small sample size, and the lack of a control group. However, to the best of our knowledge, this is the first study to report the mid-term benefits of more than 5 years of modified SPSD. A larger study is needed to identify the ideal decompression surgery for DLSS.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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