ORIGINAL ARTICLE doi: 10.2176/jns-nmc.2025-0130

Neurol Med Chir (Tokyo) 66, 107-115, 2026 Online January 9, 2026

Full-endoscopic Laminotomy Is Effective for Lumbar Spinal Stenosis with Low-grade Spondylolisthesis: A Comparative Cohort Study

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Abstract

The optimal management of lumbar spinal canal stenosis with spondylolisthesremains controversial, particularly when choosing between decompression alone or decompression with fusion. Current evidence is based on conventional open or endoscopy-assisted surgeries, with limited data on full-endoscopic decompression. This study aimed to assess the impact of spondylolisthesis on outcomes after full-endoscopic laminotomy by evaluating back pain-related disability scores in patients with lumbar spinal canal stenosis, with and without spondylolisthesis. A retrospective analysis was conducted at Iwai Orthopaedic Hospital, Japan. Patients with lumbar spinal canal stenosis who underwent full-endoscopic laminotomy between January 2021 and December 2022 were included and categorized into those without spondylolisthesis and those with spondylolisthesis. Postoperative Oswestry Disability Index scores at 2 years were compared in the groups using multivariable linear regression, adjusting for confounding factors. Exploratory analyses were also conducted to identify factors affecting the Oswestry Disability Index in the patients with lumbar spinal canal stenosis with spondylolisthesis group. Statistical significance was set at $p < 0.05$. The study included 80 patients, with 40 in each group. Both groups showed improved postoperative Oswestry Disability Index. There was no significant association between spondylolisthesis and postoperative Oswestry Disability Index. However, cauda equina redundancy negatively affected postoperative Oswestry Disability Index improvement in the patients with lumbar spinal canal stenosis with spondylolisthesis group. Full-endoscopic laminotomy is an effective surgical option for lumbar spinal canal stenosis, leading to significant alleviation of disability and improvements in quality of life, regardless of spondylolisthesis. Full-endoscopic laminotomy may offer similar functional improvements regardless of the presence of low-grade spondylolisthesis, supporting its role as a less invasive alternative to fusion.

Keywords: full-endoscopic spine surgery, spondylolisthesis, full-endoscopic laminotomy, minimally invasive, lumbar spinal canal stenosis

Introduction

The management of lumbar spinal canal stenosis (LSCS) with spondylolisthesis remains controversial, particularly regarding the choice between decompression alone or decompression with fusion.[1,2)] The prevalence of spondylolisthesis complicates surgical management because of potential instability and the possible need for spinal fusion. According to the North American Spine Society (NASS) guidelines, low-grade symptomatic single-level degenerative spondylolisthesis treated with decompression alone, while preserving midline structures, yields outcomes comparable

Received April 24, 2025; Accepted October 16, 2025

to those achieved with surgical decompression and fusion with Grade B recommendation.[3] However, this evidence is primarily derived from conventional open or endoscopy-assisted surgeries, with limited data from full-endoscopic decompression procedures.

Several recent randomized controlled trials have indicated the equivalent efficacy of endoscopic surgeries to that of conventional microsurgical techniques for the treatment of lumbar disc herniation and of LSCS.[4-8] These studies have also reported that endoscopic surgery causes less postoperative pain, reduced pain medication requirement, decreased postoperative work disability, shorter hospital stays, and a lower risk of complications. These benefits are attributed to the minimally invasive nature of endoscopic surgery, including reduced tissue damage and smaller incisions. Because endoscopic surgeries have proved their potential and established their role in spine surgery, they are increasingly considered a preferable alternative for the treatment of LSCS. Uniportal full-endoscopic spine surgery (FESS), which is the least invasive endoscopic surgery, has expanded its application beyond lumbar disc herniation to degenerative diseases, driven by advancements in camera technology and instrument development. Full-endoscopic laminotomy (FEL) for lumbar spinal stenosis has shown outcomes comparable to those of traditional methods and micro-endoscopic laminotomy.[9-12] Moreover, FESS, including FEL, offers high-resolution visualization, contributing to lower perioperative and postoperative complication rates than other minimally invasive and conventional spine surgery.[13] Understanding the factors influencing FEL success in patients with spondylolisthesis is crucial to tailor surgical approaches, improve patient outcomes, and guide clinical decision-making, underscoring the need for further research.

We therefore aimed to evaluate the back pain-related disability post FEL in patients with LSCS, both with and without spondylolisthesis, to determine how spondylolisthesis affects FEL outcomes and whether decompression alone is sufficient. Our secondary objective was to identify the factors influencing back pain-related disability scores in patients with LSCS and spondylolisthesis to predict success and inform future clinical practice.

Materials and Methods

Design, setting, and ethics

This retrospective cohort study was designed to compare back pain-related disability scores in patients with LSCS. The study was conducted at the Iwai Orthopaedic Hospital, a specialized center for spinal surgeries in Japan. This setting enabled a consecutive collection of surgical cases.

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The study protocol was approved by the institutional review board of the Iwai Orthopaedic Hospital (institutional review board approval number: 20200507). Informed consent was obtained from all the patients during the surgical procedure.

Data source and population

Data were sourced from hospital medical records, encompassing consecutive surgical cases in patients diagnosed with LSCS who underwent surgery between January 2021 and December 2022 at Iwai Orthopaedic Hospital. The dataset included detailed information on patient demographics, clinical characteristics, surgical procedures, and pre- and postoperative outcomes.

We included patients diagnosed on the basis of clinical evaluation, imaging studies, and magnetic resonance imaging (MRI) scans confirming spinal canal narrowing; with symptoms consistent with neurogenic claudication or radiculopathy, such as leg pain, numbness, and weakness, exacerbated by walking and relieved by sitting or bending forward; and with availability of complete medical records, including pre- and postoperative Oswestry Disability Index (ODI) scores and EuroQol-5 Dimension (EQ-5D) questionnaire. All patients with LSCS without spondylolisthesis or LSCS with Meyerding grade 1-2 spondylolisthesis were considered candidates for our procedure, except in cases when general anesthesia posed significant risks and in those with severe instability on functional lumbar radiography. For each patient, we determined the operative strategy at a conference attended by a minimum of 4 highly experienced spine surgeons. We excluded patients with nondegenerative spondylolisthesis (isthmic or congenital) without stenosis, trauma, infection, or malignancy. Patients in whom FEL was performed at multiple levels were also excluded.

Clinical evaluation

The symptoms were categorized into 3 groups based on a previous report: radiculopathy only, cauda equina syndrome only, and mixed presentation.[14] To evaluate the MRI findings, we used previously reported classification systems for both central and lateral recess stenosis.[15-17]

Surgical procedure

FEL, a type of FESS, uses a single small incision with water irrigation for lumbar spinal stenosis. This minimally invasive approach yields reduced muscle damage and requires the removal of a smaller volume of bone tissue. Although definitive evidence regarding the efficacy of continuous water irrigation during surgery remains elusive, this technique facilitates the control of minor bleeding and maintains a clear surgical field.[12] These advantages render FEL potentially more minimally invasive than endoscopy-assisted procedures such as micro-endoscopic laminotomy, which uses a single larger skin incision without water irrigation, and unilateral biportal endoscopy, which requires 2

small skin incisions with water irrigation.[18]

The basic operative procedure has been described previously.[9,12,19] Bilateral decompression through a unilateral approach was performed, and the bilateral ligamentum flavum (LF) was removed in all cases. All procedures were performed by a well-experienced, board-certified spine surgeon (H.K.), who has performed more than 1,000 FESS surgeries. Although FESS provides surgeons with a detailed view of the surgical site, it is important to note that the field of vision is relatively limited. Consequently, it can be challenging to detect unexpected adverse events occurring outside the immediate surgical field. Therefore, we used motor-evoked potential monitoring throughout the procedure. Moreover, a fluoroscope was placed across the center of the operative table for the duration of the surgery, providing real-time imaging guidance. Under general anesthesia, the patients were carefully log-rolled into the prone position. A 12-mm skin incision was performed 10 mm lateral to the midline of the target vertebral level under fluoroscopic guidance. The muscles attached to the lower margin of the cranial vertebral laminae (VL) and the upper margin of the caudal VL were carefully detached using a dilator in a manner similar to the micro-endoscopic surgical technique.[20] Subsequently, an angled-working sheath and a 6.4-mm working channel endoscope were inserted into the exposed VL. The cranial and caudal VL, along with the inferior and superior articular processes, were removed using a 4.0-mm diameter high-speed drill (NSK Nakanishi Japan, Tokyo, Japan) to expose the LF. The boundary was dissected using a curved dissector to ensure that there was no adhesion to the underlying neural structures. The central part of the LF was carefully separated using a small curette and Kerrison rongeur. After confirming the absence of adhesion to the underlying dura mater using a dissector or blunt hook, the separated LF fragments were removed using forceps and a Kerrison rongeur. After decompression, the endoscope and working sheath were carefully removed, and a drain was placed. The skin was sutured using a single suture.

Outcome measures and surgical complications

The primary outcome measure was the ODI score 2 years after surgery. The ODI is a validated tool used to assess disabilities related to low back pain, ranging from 0 to 100, with higher scores indicating greater disability. In this study, ODI scores were measured at 2 distinct timepoints: preoperatively and 2 years postoperatively. This measure evaluates multiple dimensions of disability, including pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual activity, social life, and travel.

The secondary outcome was the quality of life (QOL) score 2 years after surgery. This was evaluated using the EQ-5D questionnaire, which measures 5 dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. The EQ-5D scores were recorded preoperatively and 2 years postoperatively. Follow-up data at 2 years were collected through outpatient visits or remote follow-up (telephone or email), given the nationwide referral pattern of the hospital. We attempted to collect these data from all patients who underwent FEL during this period. Patients without preoperative and 2-year postoperative ODI or EQ-5D were excluded. Documented intraoperative and postoperative complications such as infection, dural tears, and reoperation rates were tracked throughout the follow-up period.

Statistical analysis

Descriptive analyses were conducted to summarize the study population. Patient demographics (age and sex) and clinical characteristics (preoperative ODI, EQ-5D scores, symptoms, and radiological findings) were summarized using means and standard deviations for continuous variables, and frequencies and percentages for categorical variables. The preoperative and 2-year postoperative ODI and EQ-5D scores were compared in the LSCS without spondylolisthesis (SL-negative) and LSCS with spondylolisthesis (SL-positive). Multivariable linear regression analysis adjusted for confounding factors was used to calculate the coefficients of 2-year postoperative ODI and EQ-5D score between the groups, along with 95% confidence intervals. We conducted several sensitivity analyses to evaluate the robustness of the findings. Logistic regression was performed to determine the factors associated with achieving the minimum clinically important difference (MCID) in ODI, defined as an improvement of 12.8 points after lumbar surgery.[21] Logistic regression analysis was also conducted to evaluate the factors associated with achieving the Patient Acceptable Symptom State (PASS).[22] In addition, logistic regression was performed to evaluate the factors associated with achieving the PASS specifically for the Asian population.[23]

As an exploratory analysis, the factors influencing the FEL postoperative ODI in the SL-positive group were analyzed using multivariable regression models. Measurements of components of the O-DISC system used to assess preoperative instability related to lumbar spondylolisthesis[24] were taken to explore the factors affecting the outcome of FEL in patients with LSCS with spondylolisthesis, as follows:

- Disc height on lateral lumbar spine radiographs: preserved (≥6.5 mm) or stenotic (<6.5 mm)
- Intervertebral disc translation on lateral lumbar radiographs: ≥4 mm or <4 mm
- Intervertebral disc angle on flexion radiograph: kyphotic/neutral or lordotic
- Low back pain on a visual analog scale: ≥5 of 10 or <5 of 10
- Presence or absence of facet effusion

All statistical analyses were conducted using Stata 18 software (StataCorp LLC, College Station, TX, USA). Statis-

Table 1 Baseline Characteristics of the Patients

Characteristic	SL-Negative (n = 40)	SL-Positive (n = 40)	p-Value
Age, mean ± SD (years)	69.0 ± 9.6	69.0 ± 8.0	1.000
Sex, n (%)			0.485
Male	27 (67.5%)	24 (60.0%)	
Female	13 (32.5%)	16 (40.0%)	
Preoperative ODI, mean ± SD	35.9 ± 16.0	40.9 ± 15.6	0.158
Preoperative EQ-5D, mean ± SD	0.62 ± 0.16	0.55 ± 0.13	0.022
Symptoms			0.561
Radiculopathy only, n (%)	32 (80%)	28 (70%)	
Cauda equina syndrome only, n (%)	1 (2.5%)	1 (2.5%)	
Mixed, n (%)	7 (17.5%)	11 (27.5%)	
Symptom side			0.072
Unilateral, n (%)	18 (45%)	14 (35%)	
Bilateral, n (%)	22 (55%)	26 (65%)	
Neurogenic intermittent claudication, n (%)	20 (50%)	20 (50%)	1.000
Meyerding grade			
Grade 1, n (%)	NA	37 (92.5%)	NA
Grade 2, n (%)	NA	3 (7.5%)	NA
MRI findings			
Central stenosis			0.634
Grade A, n (%)	0 (0%)	0 (0%)	
Grade B, n (%)	16 (40%)	12 (30%)	
Grade C, n (%)	19 (47.5%)	23 (57.5%)	
Grade D, n (%)	5 (12.5%)	5 (12.5%)	
Lateral recess stenosis			0.003
Grade 0, n (%)	0 (0%)	0 (0%)	
Grade 1, n (%)	10 (25%)	0 (0%)	
Grade 2, n (%)	25 (62.5%)	32 (80%)	
Grade 3, n (%)	5 (12.5%)	8 (20%)	

EQ-5D: EuroQol 5-Dimension; MRI: magnetic resonance imaging; ODI: Oswestry Disability Index; SD: standard deviation; SL: spondylolisthesis

tical significance was set at $p < 0.05$.

Results

Patient characteristics

This study included 80 patients who underwent FEL for LSCS between January 2021 and February 2022 and were successfully followed up for 2 years post surgery. A total of 222 patients underwent the FEL procedure during this period. Among them, 80 patients underwent both preoperative and at least 1 24-month postoperative ODI or EQ-5D assessment. The backgrounds of patients who were excluded owing to loss to follow-up are presented in Supplementary Table 1. No significant differences were observed between these patients and those who were included in the study. These patients were divided into 2 groups: LSCS without spondylolisthesis (SL-negative group; n = 40) and LSCS with spondylolisthesis (SL-positive group; n = 40). In the SL-positive group, spondylolisthesis was observed at the operated level. The baseline characteristics of the 2 groups are summarized in Table 1. The mean age was 69.0 ± 9.6 years in the SL-negative group and 69.3 ± 8.0 years in the SL-positive group. The sex distribution was similar in both groups, with 27 men (67.5%) in the SL-negative group and 24 men (60.0%) in the SL-positive group. The mean preoperative ODI scores were 35.9 ± 16.0 in the SL-negative group and 40.9 ± 15.6 in the SL-positive group. The mean preoperative EQ-5D scores were 0.62 ± 0.16 in the SL-negative group and 0.55 ± 0.13 in the SL-positive group. The distribution of symptoms was similar in the groups. In the SL-negative group, 32 patients (80%) exhibited radiculopathy only, whereas in the SL-positive group, 28 patients (70%) had radiculopathy only. Moreover, 1 patient (2.5%) in each group was diagnosed with cauda

Table 2 Comparison of ODI and EQ-5D Scores Preoperatively and 2 Years Postoperatively

Measure	Group	Preoperative (mean ± SD)	2 Years postoperative (mean ± SD)	p-Value
ODI	SL-Negative	35.9 ± 16.0	15.0 ± 14.3	<0.01
	SL-Positive	40.9 ± 15.6	16.8 ± 15.5	<0.01
EQ-5D	SL-Negative	0.62 ± 0.16	0.82 ± 0.16	<0.01
	SL-Positive	0.55 ± 0.13	0.80 ± 0.19	<0.01

EQ-5D: EuroQol-5 Dimension; ODI: Oswestry Disability Index; SD: standard deviation; SL: spondylolisthesis

equina syndrome only. Unilateral symptoms were observed in 18 patients (45%) from the SL-negative group and 14 patients (35%) from the SL-positive group. Neurogenic intermittent claudication was noted in 20 patients (50%) in both groups.

No surgical complications were observed in either group during the perioperative or follow-up period. Furthermore, no patient required reoperation due to postoperative hemorrhage or LSCS recurrence. In the SL-positive group, 12 cases were followed up for 1 year postoperatively, and 5 cases were followed up for 2 years. Among these, progression of spondylolisthesis was observed in 1 case, advancing from Meyerding grade 1 to grade 2. In the SL-negative group, 12 cases were followed up for 1 year postoperatively, and 10 cases were followed up for 2 years, with no cases showing progression of spondylolisthesis.

Surgical outcomes

ODI

The SL-negative group showed a decrease in the ODI score from a preoperative mean of 35.9 ± 16.0 to a postoperative mean of 15.0 ± 14.3. The SL-positive group's ODI score decreased from a preoperative mean of 40.9 ± 15.6 to a postoperative mean of 16.8 ± 15.5 (Table 2).

EQ-5D

The EQ-5D scores increased in both groups. The SL-negative group's mean score increased from 0.62 ± 0.16 preoperatively to 0.82 ± 0.16 postoperatively. In the SL-positive group, the mean score increased from 0.55 ± 0.13 preoperatively to 0.80 ± 0.19 postoperatively (Table 2).

Comparative analysis

Spondylolisthesis and surgical outcomes

Linear regression analysis adjusted for potential confounders (age, sex, baseline ODI score, laterality, surgical level, and presence of redundancy) showed no significant association between the presence of spondylolisthesis and the postoperative ODI or EQ-5D scores (Table 3). Sensitivity analysis showed that factors such as listhesis, age, sex, body mass index, surgical side, and level were not significantly associated with achieving the MCID or PASS (Supplementary Table 1).

Table 3 Adjusted Mean Differences in Outcomes between the Groups

Outcome	Coefficient (95% CI)	p-Value
ODI Improvement	−1.7 (−4.2 to 7.9)	0.552
EQ-5D Improvement	0.02 (−0.10 to 0.06)	0.662

CI: confidence interval; EQ-5D: EuroQol-5 Dimension; ODI: Oswestry Disability Index

Factors affecting surgical outcomes in SL-positive group

In the SL-positive group, exploratory analysis identified cauda equina redundancy as a significant factor affecting postoperative ODI improvement (Table 4). This study did not support an association between other factors, including those used to assess preoperative instability, and surgical outcomes in the SL-positive groups.

Discussion

FEL relieved the disability and improved the QOL of patients 2 years after surgery, and such beneficial long-term effects were not affected by spondylolisthesis. Furthermore, the surgical complication, including the reoperation, was not observed. This suggests that patients with LSCS and Meyerding grade 1-2 spondylolisthesis, without severe instability, would likely benefit from FEL to the same extent as those with LSCS alone. To the best of our knowledge, this is the first study to address the importance of spondylolisthesis in FEL in LSCS.

Previous studies have established the efficacy of FEL for LSCS, reporting significant improvements in pain relief, functional outcomes, and patient satisfaction, which indicated that FEL can be a reasonable surgical option for LSCS without spondylolisthesis.[7,25] Several studies have reported the reasonable safety and clinical outcomes of FEL for LSCS compared with microscopic decompression or micro-endoscopic laminectomy (MEL).[26,27] In addition, FEL has been reported to cause rapid pain relief.[26,27] This can be speculated to be due to the less invasive nature of FEL.

Table 4 Factors Affecting Postoperative ODI in the SL-Positive Group

Factor	Coefficient (95% CI)	p-Value
Meyerding grade		
Grade 1	Ref	-
Grade 2	6.57 (−9.43 to 22.57)	0.406
Background		
Age	0.33 (−0.26 to 0.93)	0.261
Sex	18.55 (4.14 to 32.96)	0.014
BMI	0.39 (−1.18 to 1.97)	0.61
Preoperative ODI	0.19 (−0.17 to 0.55)	0.288
Operative side		
Right	Ref	-
Left	−5.07 (−14.00 to 3.85)	0.253
Level		
L2/3	Ref	-
L3/4	31.99 (5.62 to 58.36)	0.019
L4/5	22.31 (0.10 to 44.52)	0.049
L5/S	None	-
Redundancy	18.29 (3.12 to 33.46)	0.02
O-DISC		
Disc height	1.51 (−8.34 to 11.37)	0.754
Disc translation	−10.60 (−28.38 to 7.18)	0.231
Disc angle	2.78 (−8.87 to 14.42)	0.627
Low back pain VAS	11.15 (−1.69 to 23.99)	0.086
Facet effusion	6.03 (−4.45 to 16.51)	0.247

BMI: body mass index; CI: confidence interval; ODI: Oswestry Disability Index; Ref: reference; SL: spondylolisthesis; VAS: visual analog scale

In terms of conventional decompressive surgery, previous studies have shown minimal differences in the outcomes between patients with and those without spondylolisthesis.[1,28] Functional improvement by MEL is similar in patients with LSCS with and without spondylolisthesis.[29] These studies raise the idea that FEL has the potential to provide a reasonable treatment effect for LSCS regardless of spondylolisthesis. However, few studies have addressed the effect of spondylolisthesis on FEL outcomes. This study extends the existing knowledge by showing that FEL is reasonably beneficial for patients with LSCS with concomitant spondylolisthesis.

The latest NASS guidelines emphasize the importance of preserving midline structures in surgical decompression without fusion for lumbar spondylolisthesis.[3] From the viewpoint of midline structure preservation, FEL can be an ideal strategy. It can spare posterior elements such as the paravertebral muscles and ligaments. Compared with conventional decompressive surgery and MEL, FEL has a strong advantage in terms of invasiveness. Our study indicates that the treatment effect of FEL might not be affected by spondylolisthesis and that FEL can be considered a reasonable treatment option for patients with LSCS with spondylolisthesis.

We also speculate that the preservation of the fibrous capsule of the facet joint could be a potential benefit of FEL for LSCS with spondylolisthesis. Preservation of the facet joint in surgery for LSCS is considered beneficial from the viewpoint of postoperative stability.[30] On the basis of this idea, facet joint preservation has been reported as an advantage of several less invasive decompressive open surgeries.[31-34] The minimally invasive nature and high-resolution visualization capabilities of FEL allow us to minimize the violation of both the facet joint and the fibrous capsule. Although the benefits of fibrous capsule preservation have not been extensively studied or discussed in detail, they have the potential to be more advantageous than facet preservation. This could be another significant benefit of FEL in the treatment of LSCS with spondylolisthesis.

Our exploratory analysis identified that cauda equina redundancy limited ODI improvement in patients with LSCS with spondylolisthesis. Cauda equina redundancy is believed to show mechanical compression of the nerve root.[35,36] An autopsy study suggested that cauda equina redundancy may contribute to degeneration of nerve fibers.[36] Although cauda equina redundancy is relatively common in patients with LSCS,[37] the impact of cauda equina redundancy on decompression surgery for LSCS remains controversial. Some reports suggest that the impact of cauda equina redundancy on the surgical outcome of decompression surgery for LSCS is limited.[38,39] Conversely, cauda equina redundancy can be a prognostic indicator of worse postoperative functional recovery.[37,40] However, to the best of our knowledge, the effect of cauda equina redundancy on the surgical outcome of LSCS with spondylolisthesis has not yet been addressed. Therefore, it is unclear whether the impact of cauda equina redundancy is specific to the outcomes of FEL, or whether it applies to all types of surgical procedures, including conventional decompression surgery and MEL. Further studies are required to address this issue.

Unlike patients with LSCS with spondylolisthesis, spinal canal stenosis can be caused not only by hypertrophy of the LF and/or osteophytes but also by the slippage of the vertebra.[41] We speculate that mechanical compression induced by LSCS with spondylolisthesis can cause more severe degeneration of nerve fibers than that induced by LSCS without spondylolisthesis. This may explain the results of the present study. Although our study cannot address this speculation, and future studies are needed, we should recognize that cauda equina redundancy can influence the surgical outcome of FEL for LSCS with spondylolisthesis.

Other exploratory analyses showed that preoperative instability evaluated using the O-DISC system did not affect

surgical outcomes. The O-DISC system is a newly established objective method used to assess spondylosis instability.[24] These results suggest that decompression by FEL without fixation can provide a reasonable treatment effect for LSCS with spondylolisthesis irrespective of instability.

For the interpretation of this study, it is important to note that most cases in the SL-positive group were classified as Meyerding grade 1, indicating mild spondylolisthesis. Therefore, our results cannot be generalized to all cases of spondylolisthesis, and the effectiveness of FEL for severe spondylolisthesis is beyond the scope of this study.

Several limitations of this study should be considered when interpreting its results. First, the retrospective design may have introduced selection bias and limited the ability to establish causality. Second, the sample size was relatively small, particularly for the subgroup analyses, which may have affected the generalizability of the findings. Third, the study was conducted at a single specialized center, which may limit the applicability of the results to other settings. Fourth, the follow-up period may not reflect the long-term results and complications. Fifth, our study evaluated only 1 timepoint, which limited our understanding of the recovery trajectory and early postoperative improvements. We need to recognize that these limitations can potentially induce bias and limit the generalizability of the findings. Future studies with larger multicenter cohorts and longer follow-up periods are needed to validate these findings and further elucidate the factors influencing FEL outcomes in patients with LSCS with spondylolisthesis.

Conclusion

This study showed that FEL might be an effective surgical option for patients with LSCS, yielding significant improvements in disability and QOL, regardless of the presence of low-grade spondylolisthesis. This suggests that FEL can provide adequate decompression without additional stabilization procedures. Clinicians could consider FEL as a viable treatment option for patients with LSCS, including those with low-grade spondylolisthesis, while paying attention to specific factors such as cauda equina redundancy that may influence postoperative outcomes. These results have important implications for the surgical management of LSCS, offering a minimally invasive alternative with favorable outcomes.

Acknowledgments

We thank all the operating room staff for their technical assistance and the medical record clerks who helped collect patient data. We also thank the radiological department staff for recording the CT and MRI data. In addition, we thank Takao Yasuhara for coordinating the first author's fellowship at the Iwai Orthopaedic Medical Hospital.

Author Contributions

Kyohei Kin and Ryoji Tominaga designed the study, the main conceptual ideas, and the proof outline. Kyohei Kin, Ryoji Tominaga, and Hisashi Koga collected the data. Hisashi Koga supervised the project. Kyohei Kin and Ryoji Tominaga wrote the manuscript with support from Hisashi Koga. All authors discussed the results and commented on the manuscript.

Conflicts of Interest Disclosure

All authors have no conflict of interest.

Availability of Data and Materials

The datasets are available from the corresponding author on reasonable request.

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