Clinical Study

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Special issue

Minimally invasive biportal endoscopic spinal surgery for central canal stenosis in low-grade degenerative lumbar spondylolisthesis: clinical outcomes and implications: a retrospective observational study

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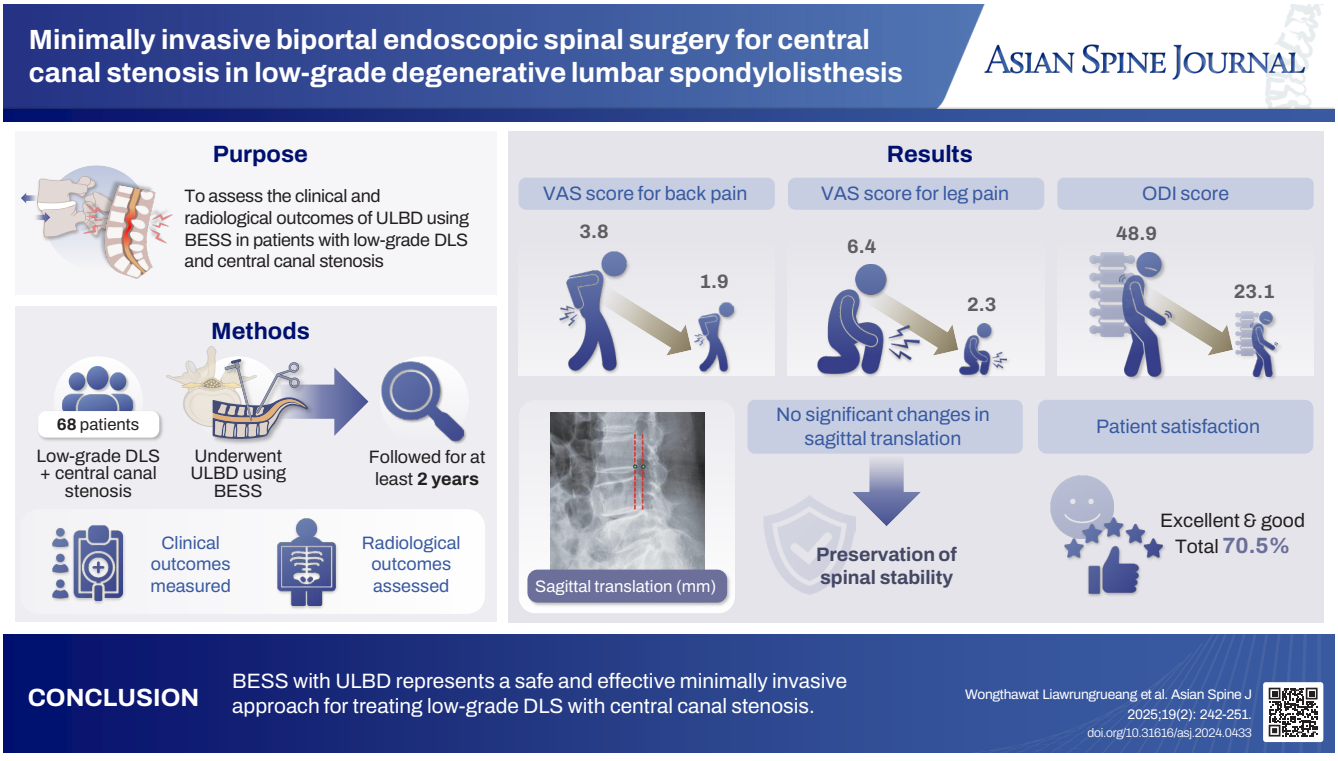

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Minimally invasive biportal endoscopic spinal surgery for central canal stenosis in low-grade degenerative lumbar spondylolisthesis: clinical outcomes and implications: a retrospective observational study

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Study Design: A retrospective observational study.
Purpose: To assess the clinical and radiological outcomes of unilateral laminotomy for bilateral decompression (ULBD) using biportal endoscopic spinal surgery (BESS) in patients with low-grade degenerative lumbar spondylolisthesis (DLS) and central canal stenosis.
Overview of Literature: DLS with central canal stenosis frequently requires surgical intervention to alleviate symptoms. Although traditional fusion surgeries are effective, they are associated with risks such as adjacent segment disease and increased postoperative morbidity. BESS presents a minimally invasive alternative that aims to achieve adequate decompression while preserving segmental stability.
Methods: A total of 68 patients with symptomatic, low-grade DLS and moderate-to-severe central canal stenosis underwent ULBD using BESS. Patients were followed for at least 2 years. Clinical outcomes were measured using the Visual Analog Scale (VAS) for back and leg pain, the Oswestry Disability Index (ODI), and the modified Macnab criteria for patient satisfaction. Radiological outcomes were assessed on the basis of sagittal translation from dynamic flexion–extension radiographs.
Results: The mean VAS score for back pain decreased from 3.8±2.4 preoperatively to 1.9±2.0 at the final follow-up, and the leg pain scores decreased from 6.4±1.8 to 2.3±2.0 (both $p<0.05$). The ODI score improved significantly from 48.9±15.7 preoperatively to 23.1±17.5 at the final follow-up ($p<0.05$). According to the modified Macnab criteria, 27.9%, 42.6%, 22.1%, and 7.4% of the patients reported excellent, good, fair, and poor outcomes. Radiological assessments indicated no significant changes in sagittal translation, supporting the preservation of spinal stability.
Conclusions: BESS with ULBD represents a safe and effective minimally invasive approach for treating low-grade DLS with central canal stenosis. It offers substantial symptom relief and functional improvement without jeopardizing spinal stability, making it a viable alternative to conventional fusion surgery.

Keywords: Neuroendoscopy; Spodylolisthesis; Spinal stenosis; Minimally invasive surgical procedure; Treatment outcome

Introduction

Degenerative lumbar spondylolisthesis (DLS) is a prevalent spinal condition characterized by the forward slippage of a vertebral body relative to the adjacent vertebra [1,2]. DLS predominantly affects older adults and is commonly associated with central canal stenosis, leading to debilitating symptoms, including chronic low back pain, radiculopathy, and neurogenic claudication. These symptoms significantly compromise patients' quality of life, often requiring surgical intervention when conservative treatments fail [3].

The traditional surgical management for DLS with central canal stenosis often involves decompression with or without spinal fusion. Although these approaches effectively relieve neural compression and offer stability, they are associated with certain risks, such as adjacent segment disease (ASD), prolonged recovery time, and increased operative morbidity. Furthermore, fusion surgeries can accelerate degeneration at adjacent levels, potentially requiring additional surgical interventions, particularly in older patients with limited physiological reserve [4-6]. Therefore, the need for minimally invasive surgical alternatives that provide equivalent outcomes with reduced morbidity is increasing.

Biportal endoscopic spinal surgery (BESS) has recently emerged as an innovative minimally invasive technique that addresses these concerns. Unlike conventional open surgeries, BESS utilizes two small portals, allowing for the direct visualization of the operative field and precise decompression of neural elements [7,8]. This approach minimizes disruption to the surrounding paraspinal muscles and ligamentous structures, thereby preserving segmental stability. Unilateral laminotomy for bi-

lateral decompression (ULBD), a key technique within the BESS framework, facilitates comprehensive neural decompression through a unilateral approach, further reducing the risk of iatrogenic instability.

Although BESS has demonstrated promising results in various spinal pathologies, limited evidence shows the efficacy and safety in treating low-grade DLS with central canal stenosis. The existing literature predominantly focuses on other minimally invasive spinal surgical techniques, and few studies have evaluated the potential advantages of the biportal approach. This study aimed to bridge this gap by providing a detailed analysis of the clinical and radiological outcomes following ULBD via BESS in patients with low-grade DLS.

In this retrospective observational study, we hypothesized that ULBD with BESS offers significant clinical improvement and maintains spinal stability, challenging the conventional paradigm that fusion is needed for managing symptomatic DLS. By analyzing patient-reported outcomes, functional scores, and radiological parameters, this study aimed to contribute to the growing body of evidence supporting minimally invasive spine surgery, thereby promoting a shift toward less invasive yet effective surgical options for spinal disorders.

Materials and Methods

Study design

This retrospective observational analysis was conducted at a Chungnam National University Hospital. This study aimed to evaluate the clinical and radiological outcomes of BESS with unilateral laminotomy for ULBD in patients with low-grade DLS and concurrent central canal stenosis. The study involved procedures performed between January 2015 and December 2018, with a minimum follow-up period of 2 years for all participants. Informed consent was obtained from all individual participants included in the study. Ethical clearance was obtained from the Institutional Review Board (IRB) (IRB no., 2023-01-046), and all procedures adhered to the principles of the Declaration of Helsinki.

Inclusion and exclusion criteria

Patients were eligible for inclusion if they satisfied the following criteria: aged between 18 and 80 years; diagnosed with symptomatic, low-grade (Meyerding grade I) DLS [9] accompanied by moderate-to-severe central canal stenosis, verified by magnetic resonance imaging (MRI) and the lumbar central canal stenosis grading system [10]; demonstrated inadequate symptom relief following a minimum of 3 months of conservative management, including physical therapy, nonsteroidal anti-inflammatory drugs, or epidural steroid injections; and lacked a significant segmental instability [11], defined as <4.5 mm of sagittal translation or <15° of angulation on dynamic flexion–extension radiographs. The exclusion criteria were as follows: high-grade spondylolisthesis (Meyerding grade II or higher) [9], severe foraminal stenosis as per the Wildermuth classification [10], scoliosis with a Cobb angle >30°, previous lumbar spine surgery at the affected segment, and any coexisting pathology such as infection, tumor, trauma, or metabolic bone disorders. Sixty-eight patients meeting these criteria were included in the study.

Surgical technique

All surgical interventions were implemented by an experienced spine surgeon proficient in minimally invasive procedures. Under general anesthesia, the patients were positioned prone on a radiolucent operating table. BESS was employed to perform ULBD. Two incisions (each approximately 1 cm long) were made on either side of the affected vertebral level. One portal facilitated endoscopic visualization, and another portal allowed the insertion of surgical instruments. Decompression involved selective resection of the hypertrophied ligamentum flavum, partial medial facetectomy, and foraminotomy, as warranted, to alleviate nerve root compression. Our surgical technique preserves 75%–85% of the medial facet joint surface intraoperatively, guided by intraoperative visualization and standard recommendations to maintain spinal stability. The facet joints and posterior midline structures were preserved to maintain spinal stability. Hemostasis was achieved using bipolar electrocautery and radiofrequency ablation. Postoperative drainage was performed as required. Mobilization was encouraged on the day of surgery, and discharge was generally scheduled for 1–2 days after surgery.

Outcome measures

Clinical outcomes were assessed using the Visual Analog Scale (VAS) for both back and leg pain, Oswestry Disability Index (ODI), and the modified Macnab criteria patient satisfaction (categorized as excellent, good, fair, or poor), based on the levels of symptom relief and functional improvement according to the patients) [12]. Radiological outcomes were determined through pre-

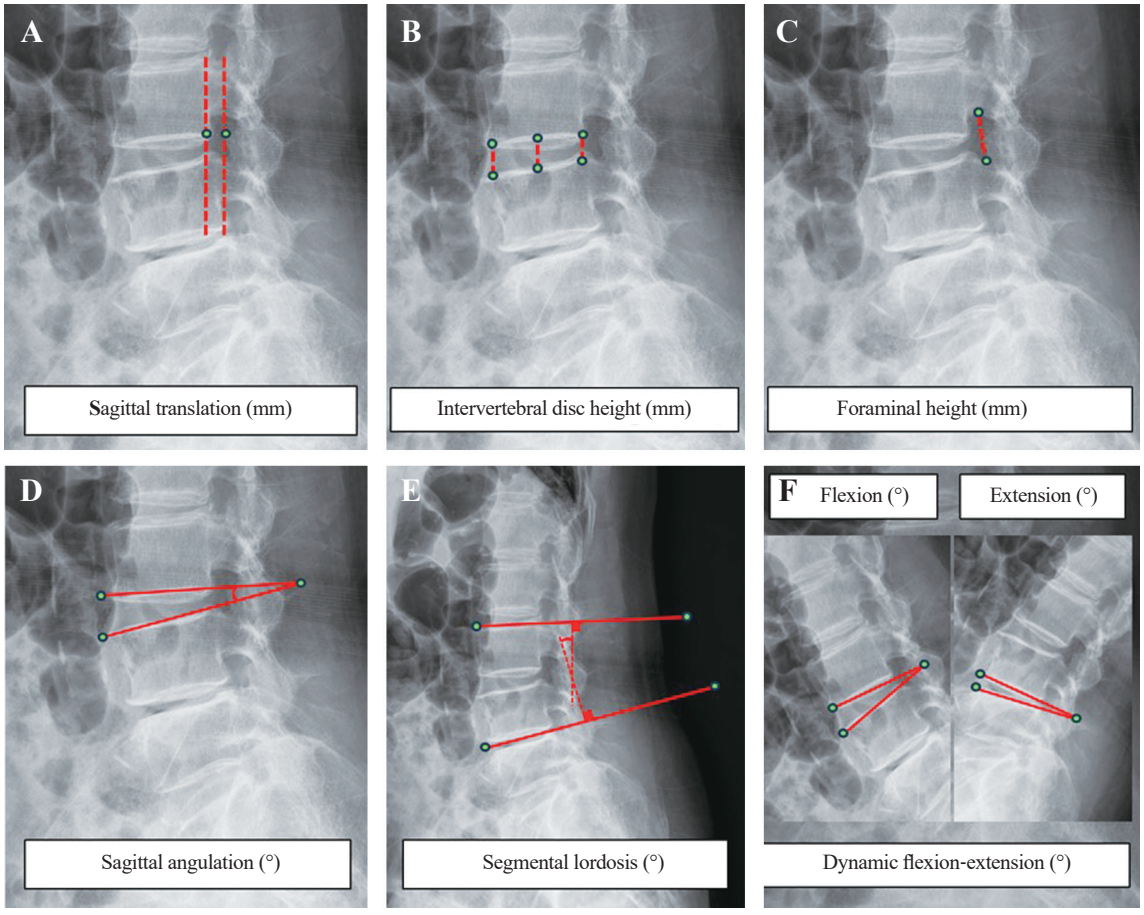

Fig. 1. (A–F) Radiological measure: sagittal translation (mm), intervertebral disc height (mm)=(anterior disc height+middle disc height+posterior disc height)÷3, foraminal height (mm), sagittal angulation (°), segmental lordosis (°), and dynamic flexion-extension (°).

operative and final follow-up dynamic flexion–extension radiographs, with measurements of sagittal translation to assess segmental stability [13,14]. Radiological parameters measured on X-ray images provide critical insights into spinal alignment and stability (Fig. 1). Sagittal translation (mm) was assessed using dynamic flexion–extension lateral X-ray images by measuring the anteroposterior displacement between the posterior edges of the adjacent vertebral bodies in flexion and extension. Sagittal angulation (°) was determined by measuring the angle between lines drawn parallel to the upper vertebra's superior endplate and the lower vertebra's inferior endplate during flexion and extension. The dynamic flexion–extension range (°) was calculated as the difference between these angles, reflecting segmental mobility. The intervertebral disc height (mm) was measured as the vertical distance between the adjacent vertebral endplates at the anterior, middle, and posterior regions of the disc space, with the average value providing the final measure.

Segmental lordosis (°) was evaluated by measuring the angle formed between the lines along the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra at the segment of interest. Finally, the foraminal height (mm), though less commonly assessed on X-ray images, can be approximated on lateral views by measuring the vertical distance between the upper and lower margins of the intervertebral foramen. Ensuring proper patient positioning and image quality is crucial for reliable and reproducible measurements. MRI scans were obtained preoperatively and postoperatively to confirm adequate decompression and exclude residual stenosis or postoperative complications that we demonstrated as an example clinical case in low-grade spondylolisthesis L4/L5 and spinal stenosis following BESS (Figs. 2, 3).

Statistical analysis

All statistical analyses were conducted using the SPSS software ver. 11.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed as means with standard deviations, and categorical variables were reported as frequencies and percentages. Paired *t*-tests were ap-

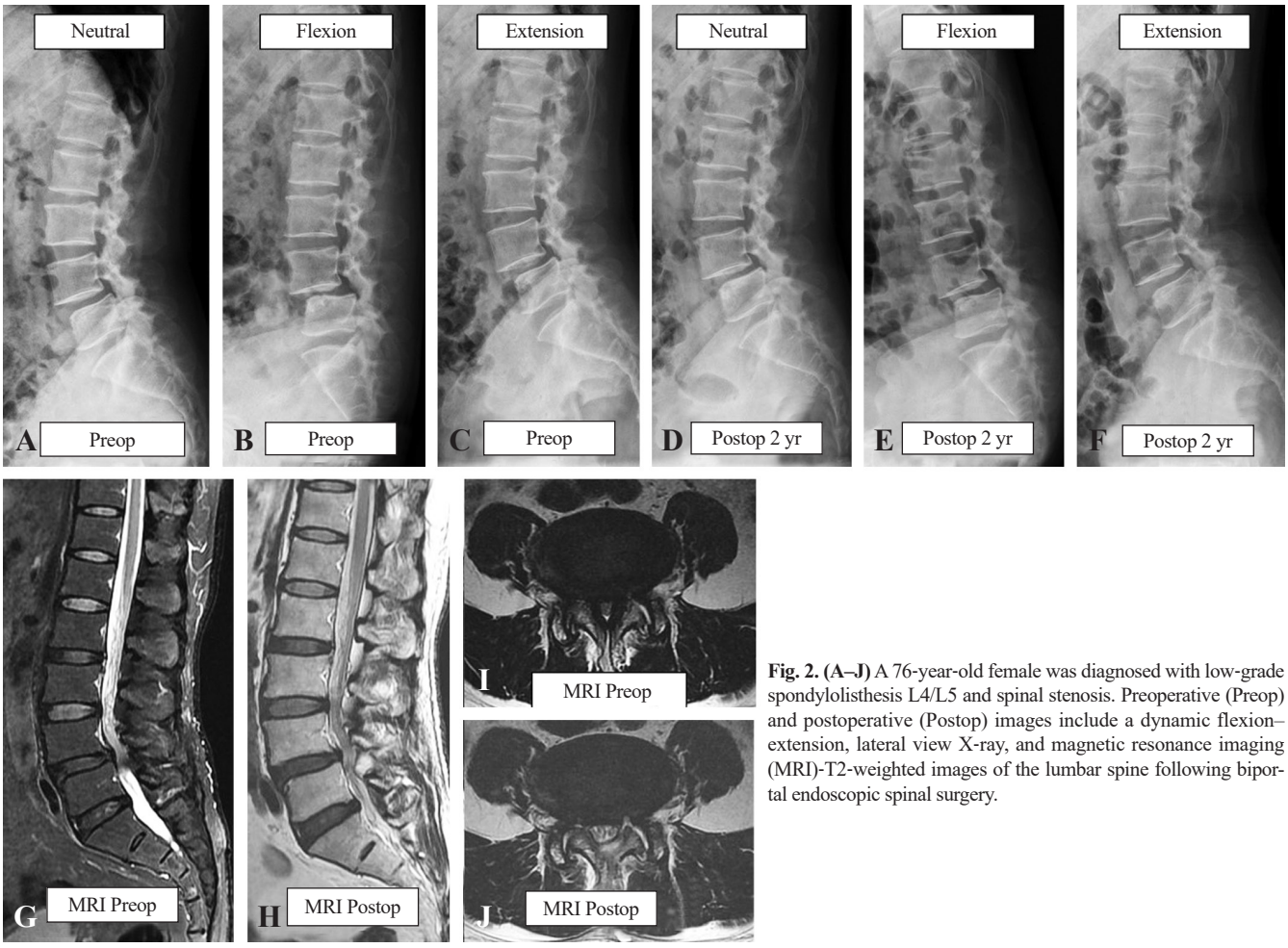

Fig. 2. (A–J) A 76-year-old female was diagnosed with low-grade spondylolisthesis L4/L5 and spinal stenosis. Preoperative (Preop) and postoperative (Postop) images include a dynamic flexion–extension, lateral view X-ray, and magnetic resonance imaging (MRI)-T2-weighted images of the lumbar spine following biportal endoscopic spinal surgery.

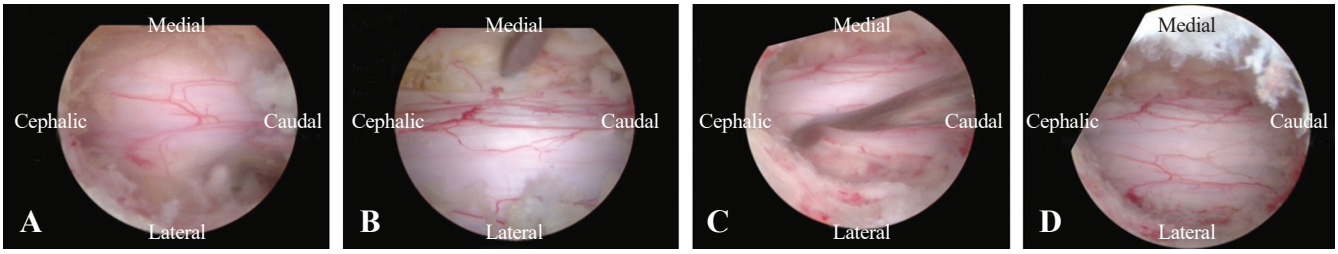

Fig. 3. Endoscopic views show the central **(A)**, contralateral side **(B)**, ipsilateral side **(C)**, and posterior decompressed status following biportal endoscopic spinal surgery **(D)**.

plied to compare the study cohort's preoperative and postoperative clinical scores. A *p*-value of less than 0.05 was regarded as statistically significant.

Results

Baseline and clinical characteristics

This study included the baseline demographic and clinical characteristics of the 68 patients (Table 1). The mean age was 67.3±10.9 years, and the male-to-female ratio was 27:41. The American Society of Sociologists classification score averaged 1.9±0.6, indicating mild-to-moderate systemic health conditions. The median hospital length of stay was 10 days (range, 6–13 days). The median follow-up duration extended to 1,052 days (range, 731–2,626 days), reflecting the long-term observation of the outcomes. The mean operative time was 62±3.8 minutes, with an average estimated blood loss of 51±5.3 mL. Most surgeries were performed at the L4–5 level (76.5%), followed by L3–4 (20.6%) and L5–S1 (2.9%). Among the patients, 56% had at least one

Table 1. Baseline demographics, clinical characteristics, and comorbidities

Characteristic	Value
Total no. of patients	68
Age (yr)	67.3±10.9
Gender	
Male	27
Female	41
ASA classification	1.9±0.6
Patients with underlying disease	38 (56.0)
Hypertension	28 (41.0)
Diabetes mellitus	15 (22.0)
Cardiovascular disease	8 (12.0)
Other (e.g., COPD, CKD)	4 (6.0)
Hospital stay (day)	10 (6–13)
Follow-up duration (day)	1,052 (731–2,626)
Operative time (min)	62±3.8
Estimated blood loss (mL)	51±5.3
Surgical level	
L3–4	14 (20.6)
L4–5	52 (76.5)
L5–S1	2 (2.9)
Meyerding classification	
Grade I	68 (100.0)
Grade II	0
Grade III	0
Grade IV	0
Grade V	0

Values are presented as number (%), mean±standard deviation, or median (interquartile).
ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease.

underlying disease, with hypertension, diabetes mellitus, and cardiovascular disease being the most common comorbidities.

Clinical and radiological outcomes

Significant improvements were observed in the clinical outcomes following BESS (Table 2). The mean VAS score for back pain decreased from 3.8±2.4 preoperatively to 1.9±2.0 at the final follow-up (p<0.05), and the VAS score for lower extremity pain decreased from 6.4±1.8 to 2.3±2.0 (p<0.05). Functional outcomes, as assessed by the ODI, improved from 48.9±15.7 preoperatively to 23.1±17.5 at the final follow-up (p<0.05), indicating substantial enhancement in functional capacity and quality of life. Radiological outcomes demonstrated

Table 2. Outcomes of clinical and radiological measurement

Outcome measure	Preoperative	Final follow-up	p-value
Clinical measure			
VAS back pain	3.8±2.4	1.9±2.0	<0.05
VAS lower extremity pain	6.4±1.8	2.3±2.0	<0.05
ODI score	48.9±15.7	23.1±17.5	<0.05
Radiological measure			
Sagittal translation (mm)	5.25±4.6	5.31±7.2	0.78
Sagittal angulation (°)	4.2±1.1	4.3±1.3	0.81
Dynamic flexion-extension (°)	8.5±2.4	8.6±2.5	0.77
Intervertebral disc height (mm)	7.2±1.6	7.1±1.5	0.69
Segmental lordosis (°)	12.6±3.4	12.8±3.5	0.74
Foraminal height (mm)	20.9±0.7	20.8±0.8	0.85

Values are presented as mean±standard deviation.
VAS, Visual Analog Scale; ODI, Oswestry Disability Index.

stability and alignment preservation over the follow-up period. Sagittal translation remained stable, with no significant differences (5.25±4.6 mm preoperatively versus 5.31±7.2 mm at final follow-up, p=0.78). Additional parameters, including sagittal angulation (4.2°±1.1° preoperatively versus 4.3°±1.3° at the final follow-up, p=0.81), dynamic flexion–extension (8.5°±2.4° preoperatively versus 8.6°±2.5° at the final follow-up, p=0.77), and segmental lordosis (12.6°±3.4° preoperatively versus 12.8°±3.5° at the final follow-up, p=0.74) showed no significant changes. The intervertebral disc height (7.2±1.6 mm preoperatively versus 7.1±1.5 mm postoperatively, p=0.69) and foraminal height (20.9±0.7 mm preoperatively versus 20.8±0.8 mm postoperatively, p=0.85) further confirmed the preservation of the segmental stability and anatomical integrity.

Postoperative complications and patient satisfaction

The postoperative complications and patient satisfaction are summarized in Table 3; postoperative complications were minimal. No major complications, such as dural tears, neurological deficits, or infections, were reported. Minor complications included transient leg weakness in three patients (4.4%), which resolved without intervention. No reoperations, readmissions, or instances of ASD were observed during the follow-up. Patients expressed high levels of satisfaction, with 70.5% of the patients rating their outcomes as "excellent" or "good" according to the modified Macnab criteria.

BESS with unilateral laminotomy for ULBD is an effective minimally invasive treatment for low-grade DLS with central canal stenosis. This approach results in significant clinical improvements while preserving spinal

Table 3. Postoperative complications and patient satisfaction (n=68)

Outcome measure	Value
Major complications	0
Minor complications	3 (4.4)
Transient numbness	2 (2.9)
Localized wound pain	1 (1.5)
Resolved without intervention	3 (100.0)
Reoperations	0
Readmissions	0
Adjacent segment disease	0
Modified Macnab criteria	
Excellent	(27.9)
Good	(42.6)
Fair	(22.1)
Poor	(7.4)

Values are presented as number (%) or (%).

stability, offering a promising alternative to traditional fusion surgeries.

Discussion

BESS is a minimally invasive surgery, and this study provides evidence supporting the efficacy and safety of BESS with ULBD in treating DLS in degenerative spinal disease [15,16]. The findings demonstrate that BESS with ULBD yields significant improvements in pain relief, functional outcomes, and patient satisfaction while maintaining spinal stability, a critical factor when considering minimally invasive alternatives to traditional fusion-based approaches.

The clinical improvements corresponded with the previously reported outcomes of endoscopic spine surgery. Specifically, pain significantly reduced, as indicated by the VAS scores, where back pain decreased from 3.8±2.4 preoperatively to 1.9±2.0 postoperatively, and leg pain improved from 6.4±1.8 to 2.3±2.0. Moreover, the ODI scores reflected substantial enhancement in functional capacity, reducing from a preoperative mean of 48.9±15.7 to 23.1±17.5 postoperatively. These data highlight the potential of BESS to ameliorate pain and improve the quality of life significantly, corroborating the efficacy of minimally invasive spine techniques reported in other studies.

The advantages of BESS can be attributed to its unique approach, which minimizes the disruption to the paraspinal musculature and preserves the ligamentous and bony structures that are essential for spinal stability [17,18]. In our cohort, radiological outcomes showed stable sagittal translation from preoperative to final follow-up, with no significant difference observed (5.25±4.6 mm preoperatively versus 5.31±7.2 mm postoperatively, p=0.78). This preservation of stability is notable because it contrasts with conventional decompression methods that can potentially compromise structural integrity and necessitate additional fusion procedures. These findings indicate the ability of BESS to effectively decompress neural elements while minimizing iatrogenic instability as a primary concern in more extensive open surgeries [18]. The possibility of iatrogenic instability and residual low back pain in this study indicated that no cases of iatrogenic instability were observed during the follow-up period, as evidenced by stable sagittal translation (5.25±4.6 mm preoperatively versus 5.31±7.2 mm postoperatively, p=0.78) and sagittal angulation (4.2°±1.1° preoperatively versus 4.3°±1.3° postoperatively, p=0.81). These results could reflect the effectiveness of BESS in preserving posterior structures, such as the facet joints and ligamentum flavum, and minimizing destabilization, even in cases requiring extensive decompression. Although the progression of instability is possible in DLS because of the natural disease course, our findings suggest that BESS does not exacerbate this process. Significant improvements in low back pain were observed, with mean VAS scores decreasing from 3.8±2.4 preoperatively to 1.9±2.0 at the final follow-up (p<0.05). However, in some cases, residual low back pain could cause degenerative changes or paraspinal muscle dysfunction rather than instability because our radiological evaluations showed no significant biomechanical compromise. Further studies utilizing advanced biomechanical assessment methods and longer follow-up periods could provide deeper insights into the potential contributors to the residual symptoms and long-term stability of BESS.

The technical approach utilized in BESS, which employs two small portals for the endoscope and surgical instruments, offers several distinct benefits. In this study, the mean estimated blood loss was relatively low at 51±5.3 mL, and the mean operative time was brief, averaging 62±3.8 minutes. These parameters, coupled with the minimal tissue disruption inherent to BESS, likely contributed to the reduced postoperative recovery time, with a median hospital stay of only 10 days (range, 6–13 days). Although the median hospital stay in our cohort was 10 days, a significant outlier was observed, with one patient requiring prolonged hospitalization of 13 days because of localized wound pain. This case highlights the importance of vigilant postoperative care and early intervention in complication management, particularly in patients with comorbidities or advanced

age. Future studies with larger cohorts are warranted to better understand and mitigate the factors that contribute to prolonged hospitalization in minimally invasive spine surgery. The prevalence at L3–4 compared with L5–S1 to a widely reported higher prevalence of DLS at the L5–S1 level. In this study, we observed a high number of cases at the L3–4 level. This discrepancy may reflect the unique patient demographics in our cohort, regional anatomical variations, or differences in lifestyle factors that predispose individuals to spondylolisthesis at the L3–4 level. For instance, occupations or activities of daily activities involving repetitive flexion–extension movements or axial loading may disproportionately affect the L3–4 segment. In addition, the imaging and diagnostic practices at our institution contributed to this finding. Such metrics reflect the potential for BESS to facilitate shorter operative times, reduced intraoperative blood loss, and expedited patient recovery—which are all consistent with the advantages generally ascribed to a minimally invasive surgical approach [19,20].

This study presented a low incidence of postoperative complications. No major complications, such as dural tears, infections, or permanent neurological deficits, were observed. Minor complications were limited to transient leg weakness in three patients (4.4%), which resolved without intervention. Importantly, no reoperations, readmissions, or ASD were observed during follow-up. These findings underscore the favorable safety profile of BESS, particularly when compared with open decompression and fusion, which are often associated with higher complication rates and more substantial postoperative morbidity [21,22].

This cohort had a high level of patient satisfaction, as assessed by the modified Macnab criteria, and 70.5% of the patients reported their outcomes as either "excellent" or "good." Given that patient satisfaction is a critical indicator of surgical success, this metric indicates that BESS aligns well with patient expectations regarding pain relief and functional recovery. The combination of minimal postoperative morbidity, substantial symptom relief, and functional capacity preservation further supports the clinical utility of BESS in managing low-grade DLS with spinal stenosis [12].

The long-term stability of BESS is a notable advantage compared with traditional fusion surgeries. BESS minimizes the disruption to the paraspinal musculature, ligamentum flavum, and posterior bony structures, reducing the ASD risk, which is often associated with fusion-based approaches. Our findings demonstrate significant changes in sagittal translation (5.25±4.6 mm preoperatively versus 5.31±7.2 mm at the final follow-up, p=0.78) over a median follow-up of 1,052 days, and align with existing literature. Choi et al. [17,20] and Ahn et al. [18] have reported that preserving posterior structures through minimally invasive techniques such as BESS contributes to maintaining segmental stability while achieving adequate neural decompression. Furthermore, evidence from the studies by Eun et al. [15] and Jitpakdee et al. [7] supports the clinical utility of BESS in preventing instability, even in multilevel stenosis cases. These findings underline that BESS effectively alleviates symptoms in low-grade DLS without compromising spinal stability, making it a viable alternative to traditional fusion, particularly in older patients or those with physiologically compromised status. Further studies with larger cohorts and extended follow-ups are warranted to confirm these promising outcomes.

This study employed a retrospective study design and had a possibility of selection bias. The relatively single-center design may also limit the generalizability of our findings. Although our follow-up period was sufficiently long for medium-term outcomes, further studies with extended follow-up durations are needed to evaluate potential late-onset complications, such as delayed instability or recurrent stenosis. Finally, this study focused on patients with low-grade DLS; thus, the applicability of BESS in high-grade spondylolisthesis or multilevel stenosis warrants further investigation. BESS with ULBD is an effective, minimally invasive approach for managing low-grade DLS with central canal stenosis. The significant clinical improvements, combined with the preserved spinal stability and a low complication rate, highlight the potential of BESS as an alternative to more invasive fusion surgeries. Given the increasing interest in minimally invasive spine surgery, BESS offers a promising avenue for improving patient outcomes while minimizing the risks associated with conventional surgical interventions. Further studies, particularly prospective randomized controlled trials, are recommended to substantiate these findings and clarify the long-term role of BESS in treating degenerative lumbar pathologies.

Conclusions

BESS with ULBD is a promising minimally invasive alternative for the treatment of stable low-grade DLS with central canal stenosis. This technique offers significant symptom relief, improves functional outcomes, and maintains spinal stability with minimal complications. Given the increasing adoption of minimally invasive spine surgery, BESS may play a pivotal role in the surgical management of lumbar degenerative conditions,

ultimately enhancing patient care and quality of life.

Key Points

- This study demonstrates that biportal endoscopic spinal surgery (BESS) with unilateral laminotomy for bilateral decompression (ULBD) offers excellent clinical outcomes in patients with low-grade degenerative lumbar spondylolisthesis and central canal stenosis.
- Patients experienced significant and sustained improvements in back and leg pain (Visual Analog Scale) and functional disability (Oswestry Disability Index) at long-term follow-up.
- Radiological findings confirmed maintained spinal stability, with no significant changes in sagittal translation or segmental alignment.
- BESS with ULBD stands out as a highly effective, minimally invasive surgical option that delivers reliable symptom relief and functional recovery while avoiding the risks of traditional fusion surgery.

Conflict of Interest

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

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Conceptualization: WL, HJL. Methodology: WL, HJL. Data curation: WL, HJL, SBK, SHL, SSL, JEK. Formal analysis: WL. Visualization: WL. Project administration: HJL. Writing–original draft preparation: WL, HJL, SBK, SHL, SSL, JEK. Writing–review and editing; WL, HJL. Supervision: HJL. Final approval of the manuscript: all authors.

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