Clinical Efficacy and Risk Factors for Complications of Unilateral Biportal Endoscopy Treatment in Complex Spinal Stenosis: A Retrospective Study

Ann. Ital. Chir., 2025 96, 10: 1365–1372
https://doi.org/10.62713/aic.4231

Yuanqing Niu[1], Hengrui Chang[1], Jiaxin Xu[1]

[1]Department of Spinal Surgery, Hebei Medical University Third Hospital, 050051 Shijiazhuang, Hebei, China

AIM: This study aimed to evaluate the clinical efficacy of unilateral biportal endoscopy (UBE) technology in patients with complex spinal stenosis and to identify factors associated with postoperative complications to optimize individualized treatment strategies.

METHODS: This single-center retrospective study included 146 patients with complex spinal stenosis, characterized by multi-segmental involvement and/or ligamentum flavum calcification, who underwent UBE between May 2020 and March 2023. Eligible patients had complete clinical and imaging data and a minimum follow-up of 6 months. Surgical variables (operative time, intraoperative blood loss, and length of hospital stay), perioperative information, and early mobilization protocols were collected. Primary outcomes included pain intensity (visual analog scale (VAS)), functional disability (Oswestry Disability Index (ODI)), and neurological recovery (Japanese Orthopaedic Association (JOA)). Secondary outcomes involved complication rates, recurrence, and patient satisfaction. Pre- and postoperative differences were assessed using paired *t*-tests, and multivariate logistic regression was performed to identify independent risk factors for postoperative complications.

RESULTS: UBE significantly improved clinical symptoms, with VAS scores decreasing from 7.5 $\pm$ 0.9 preoperatively to 2.5 $\pm$ 0.8 postoperatively ($p < 0.001$), ODI scores decreasing from 55.8 $\pm$ 8.3% to 19.6 $\pm$ 6.4% ($p < 0.001$), and JOA scores increasing from 8.7 $\pm$ 1.9 to 19.8 $\pm$ 3.1 ($p < 0.001$). Imaging evaluations showed a significant increase in spinal canal area ($p < 0.001$). The overall complication rate was 19.9% (29 cases), with ligamentum flavum calcification identified as an independent risk factor (odds ratio (OR) = 3.414, 95% confidence interval (CI): 1.383–8.432, $p = 0.008$). The satisfaction score of 88.4% of patients is $\geq$4 points.

CONCLUSIONS: UBE technology effectively improves clinical symptoms and imaging outcomes for managing complex spinal stenosis, with low complication and recurrence rates. However, the presence of ligamentum flavum calcification is a critical risk factor for complications, highlighting the need for tailored preoperative planning to optimize surgical outcomes and reduce risks.

Keywords: unilateral biportal endoscopy; complex spinal stenosis; individualized treatment; postoperative complications; minimally invasive spine surgery

Introduction

Spinal stenosis is a common degenerative spinal disease characterized by narrowing of the spinal canal, resulting in neural compression that leads to pain, functional impairment, and neurological damage [1,2]. In patients with complex spinal stenosis, multiple segments are often affected and accompanied by pathological changes such as ligamentum flavum calcification and disc herniation, making the disease course more complicated and severely impacting patients' quality of life [3–5]. Treating such cases poses significant challenges. Traditional open surgery, although effective, is highly invasive and associated with prolonged recovery and a greater risk of complications. Consequently, minimally invasive techniques have become the mainstream choice for spinal stenosis treatment in recent years [6].

Unilateral biportal endoscopy (UBE) is an emerging minimally invasive surgical method that employs independent working and viewing channels to achieve precise decompression and real-time visualization. This approach offers significant advantages in the treatment of spinal stenosis [7–9], including small incisions, reduced tissue damage, and faster postoperative recovery, making it particularly suitable for addressing complex lesions requiring precise decompression [10,11]. Previous study has demonstrated favorable outcomes with UBE in patients with single-segment or non-calcified spinal stenosis, showing significant pain relief and radiological evidence of spinal canal expansion [12]. However, its application in complex cases, especially those with multisegment involvement or ligamentum flavum calcification, still faces considerable challenges. The complexity of such lesions not only increases surgical difficulty but also significantly raises the risk of complications [13,14]. Despite increasing clinical adoption, systematic research on its efficacy, safety, and individualized

Submitted: 25 June 2025 Revised: 14 August 2025 Accepted: 28 August 2025 Published: 10 October 2025
Correspondence to: Jiaxin Xu, Department of Spinal Surgery, Hebei Medical University Third Hospital, 050051 Shijiazhuang, Hebei, China (e-mail: hemunyq@163.com).

treatment strategies of UBE for complex cases remain insufficient.

The clinical efficacy of spinal surgery is often assessed using standardized indicators. The visual analog scale (VAS) is widely applied to measure pain intensity, the Oswestry Disability Index (ODI) evaluates functional disability in daily activities, and the Japanese Orthopaedic Association (JOA) score assesses neurological recovery [15,16]. These tools provide a comprehensive evaluation of postoperative outcomes and are commonly adopted in spine-related clinical studies.

Current research has primarily focused on the application of UBE in general cases of spinal stenosis. However, two significant limitations exist regarding its application in complex lesions: (1) the absence of systematic evaluation of UBE efficacy, including imaging outcomes in patients with multisegment involvement or ligamentum flavum calcification, and (2) insufficient exploration into key risk factors influencing postoperative complications, such as the extent of calcification and the number of affected segments. These gaps hinder accurate preoperative planning and limit the development of optimized surgical strategies for complex cases, thereby restricting broader adoption of UBE technology in high-difficulty scenarios.

This study aims to systematically evaluate the clinical outcomes of UBE technology in patients with complex spinal stenosis, identify critical factors affecting surgical efficacy and complications, and explore individualized treatment strategies for complex cases. Through retrospective analysis of patient data and postoperative evaluations, this study seeks to optimize UBE treatment protocols and provide scientific evidence for the clinical management of complex cases. The findings aim to assist surgeons in devising precise preoperative plans, enhance surgical safety, and reduce postoperative complications. Furthermore, the results will contribute to the broader application of minimally invasive spinal surgery techniques in a wide range of clinical scenarios.

Materials and Methods

Study Design

This was a single-center, retrospective observational study. Between May 2020 and March 2023, 146 patients with complex spinal stenosis who met the inclusion criteria were analyzed. Patient records were anonymized and stored in an encrypted database with restricted access, limited to the core members of the research team. The study was approved by the ethics committee of Hebei Medical University Third Hospital (Approval No. KS2024-191-1), and strictly adhered to the Declaration of Helsinki and related professional ethical guidelines. Written informed consent was obtained from all of the participants in the study.

The inclusion criteria were as follows: (1) diagnosis of complex spinal stenosis by imaging studies, including but not limited to the following characteristics: multisegmental lesions, ligamentum flavum calcification, disc herniation, or severe neural compression symptoms (e.g., intermittent claudication, lower limb numbness); (2) treatment with UBE technology; (3) minimum of 6 months of follow-up with complete follow-up data available. The exclusion criteria were as follows: (1) presence of severe systemic diseases (e.g., cardiac or pulmonary insufficiency) contraindicating surgery; (2) incomplete data or interrupted follow-up; (3) spinal stenosis secondary to other conditions, such as spinal infection or tumor.

To ensure adequate statistical power, a priori sample size estimation was performed using G*Power software (version 3.1, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), based on a two-tailed paired *t*-test [17]. Assuming a medium effect size (Cohen's $d = 0.5$), yielded a required sample size of 54 ($\alpha = 0.05$, power = 95%). The final cohort (n = 146) exceeded this requirement, thereby ensuring sufficient power for both primary analyses and additional multivariate logistic regression without causing unnecessary waste of resources.

Unilateral Biportal Endoscopy Technology

In this study, all patients underwent UBE technology for treatment. The surgical procedure involved three core steps: preoperative planning, surgical implementation, and postoperative management (Fig. 1).

Preoperative planning involved comprehensive imaging evaluations with magnetic resonance imaging (MRI) to identify the lesion site, segmental range, and pathological characteristics (e.g., ligamentum flavum calcification, disc herniation). Based on imaging findings, the surgical team developed a patient-specific operative plan, including the selection of the surgical approach, decompression scope, and potential intraoperative challenges.

Surgical implementation was conducted using UBE, which employs two independent channels: one serving as the working channel and the other as the viewing channel. These channels allowed precise decompression and real-time visualization. The surgical incision, approximately 1.5 cm in size, was typically made on one side of the lesion, with the exact location determined by preoperative imaging. Under endoscopic guidance, procedures such as partial laminectomy, ligamentum flavum removal, and disc excision were performed to relieve nerve compression. In cases with ligamentum flavum calcification, careful dissection and excision were performed under endoscopic guidance to minimize damage to surrounding neural structures. For multi-segmental lesions, decompression was conducted segmentally or extended across multiple segments as clinically indicated to achieve adequate spinal canal decompression.

Postoperative management included standard antibiotic prophylaxis and wound care. For patients without dural tears or significant neurological deficits, early rehabilitation was initiated within 24–48 hours. A multi-

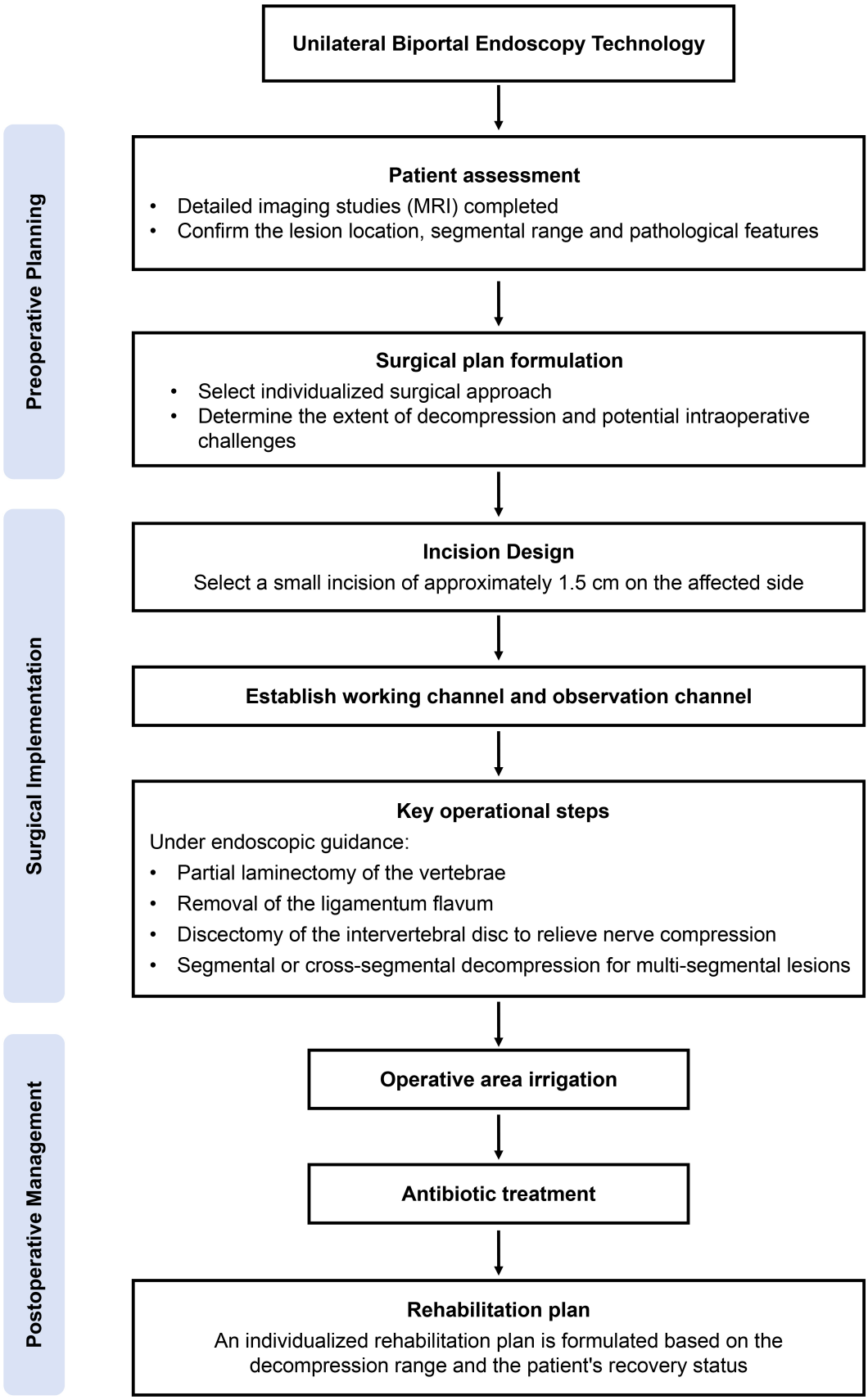

Fig. 1. Workflow of unilateral biportal endoscopy (UBE) for complex spinal stenosis.

disciplinary team—comprising spine surgeons, rehabilitation physicians, physiotherapists, and specialized spine nurses—supervised the rehabilitation process. Initial mobilization included assisted sitting, standing, and short-duration walking (5–10 minutes, two to three times daily). Patients were subsequently advanced to independent ambulation, core stability training, lower-limb strengthening, and balance exercises. In patients undergoing extensive decompression, multi-segmental surgery, or those with postoperative complications, mobilization was appropriately delayed. The intensity and progression of training were tailored according to pain control (VAS $\leq$3), absence of new neurological deficits, and functional milestones such as walking independently for at least 20 meters. Recovery progress was monitored during inpatient rounds and follow-up visits.

Data Collection

Data were obtained from the electronic medical record system and included patient baseline information, surgical data, imaging data, and follow-up results. Baseline characteristics encompassed age, sex, body mass index (BMI), lesion location (cervical, thoracic, or lumbar spine), and complexity (single- or multi-segmental lesions, presence of ligamentum flavum calcification). Surgical data included operative time, intraoperative blood loss, and length of hospital stay.

MRI was performed at two time points: (1) preoperatively, defined as the final imaging evaluation before surgery; and (2) 3 months postoperatively, to assess changes in spinal canal morphology and decompression outcomes.

Clinical symptoms data were collected at 1 day preoperatively and at 3 months postoperatively, including pain severity, functional impairment, and neurological function. All patients were followed for a minimum of 6 months. During follow-up, postoperative complications, symptom recurrence, reoperations, and patient satisfaction were documented and analyzed.

Observational Indicators

The observational indicators were divided into primary and secondary categories.

Primary indicators: clinical symptom improvement was evaluated using VAS scores for pain intensity, ODI indices for functional disability, and JOA scores for neurological function recovery. Imaging assessments were based on pre- and postoperative MRI findings, with assessments focused on spinal canal area and nerve decompression outcomes. Quantitative analysis of imaging data was conducted independently by two evaluators to ensure objectivity and reliability.

Secondary indicators: secondary indicators included postoperative complications, recurrence rates, and patient satisfaction. Complications primarily recorded adverse events such as dural tears, nerve injury, or infection. Recurrence and reoperation rates were derived from follow-up records, including the cause of recurrence and subsequent surgical interventions. Patient satisfaction was assessed through a postoperative questionnaire developed by the hospital's orthopedic department, which was based on common patient-reported outcome domains in the spine surgery literature and routinely applied in clinical follow-up. The questionnaire comprised four evaluation dimensions: (1) pain relief, (2) improvement in daily function, (3) ability to return to work or normal activities, and (4) overall satisfaction with surgical outcomes. Each dimension was rated on a 5-point Likert scale (1 = very dissatisfied, 5 = very satisfied). The overall satisfaction score was calculated as the mean of the four dimension scores. Although this tool lacked prior external validation, its internal consistency in the present cohort was acceptable (Cronbach's $\alpha = 0.82$), the percentage of collection scores $\geq$4 points.

Table 1. Baseline characteristics and surgical parameters of patients.

Characteristics	Included patients (n = 146)
Age (years)	65.8 $\pm$ 10.1
Gender (male)	87 (59.6%)
BMI (kg/m^2)	24.0 $\pm$ 3.1
Lesion distribution	
Cervical	29 (19.9%)
Thoracic	15 (10.2%)
Lumbar	102 (69.9%)
Lesion complexity	
With ligamentum flavum calcification	58 (39.7%)
Non-calcified	88 (60.3%)
Single-segment lesion	87 (59.6%)
Multi-segmental lesion	59 (40.4%)
Surgical metrics	
Operative time (minutes)	189.5 $\pm$ 36.2
Blood loss (mL)	155.0 $\pm$ 46.0
Length of hospital stay (days)	5.8 $\pm$ 2.0

Note: Data are presented as mean $\pm$ SD or n (%). BMI, body mass index.

Statistical Analysis

Statistical analysis was conducted using IBM SPSS Statistics, version 23 (IBM Corp), with a significance level set at $p < 0.05$. Baseline characteristics were summarized using descriptive statistics. Data normality was assessed using the Shapiro–Wilk test. Normally distributed continuous variables are expressed as mean $\pm$ standard deviations (SD), whereas non-normally distributed variables are presented as median (interquartile range). Categorical variables are reported as frequencies and percentages.

Within-patient pre- and postoperative comparisons of primary indicators (VAS scores, ODI indices, JOA scores, and spinal canal area) were conducted using the paired-sample *t*-test for normally distributed variables, and the Wilcoxon signed-rank test for non-normally distributed variables. Secondary indicators (complication rates, recur-

Table 2. Results of primary indicators.

Indicators	Preoperative	Postoperative	*t*-value	*p*
VAS score	7.5 ± 0.9	2.5 ± 0.8	52.419	<0.001
ODI index (%)	55.8 ± 8.3	19.6 ± 6.4	15.350	<0.001
JOA score	8.7 ± 1.9	19.8 ± 3.1	–35.079	<0.001
Spinal canal area (mm^2)	87.4 ± 12.3	161.5 ± 15.6	–44.314	<0.001

Note: Data are presented as mean ± SD. VAS, visual analog scale; ODI, Oswestry Disability Index; JOA, Japanese Orthopaedic Association.

rence rates, and patient satisfaction) were summarized descriptively using means and proportions. Logistic regression analysis was performed to identify risk factors for postoperative complications, with complication occurrence (0 = no complication, 1 = complication) as the dependent variable and patient characteristics, lesion complexity, and surgical data as independent variables. Results are expressed as odds ratios (ORs) with corresponding 95% confidence intervals (CIs).

Table 3. Results of postoperative outcomes.

Outcome measures	n (%)
Complications	29 (19.9%)
Dural tears	15 (10.3%)
Nerve injuries	7 (4.8%)
Infections	7 (4.8%)
Recurrence	14 (9.6%)
Reoperation	6 (4.1%)
Patient satisfaction (≥4 points)	129 (88.4%)

Note: Data are presented as n (%).

Results

Baseline Characteristics

A total of 146 patients with complex spinal stenosis met the inclusion criteria, underwent UBE surgery, and completed at least 6 months of follow-up. Baseline patient characteristics are summarized in Table 1. The study population showed a balanced demographic distribution, with lumbar lesions, non-calcified lesions, and single-segment lesions being the most common. Surgical metrics, including operative time and blood loss, were manageable and aligned with clinical expectations for minimally invasive surgery. These baseline data provide a robust foundation for subsequent evaluations of efficacy and risk factor analysis. They highlight the applicability of UBE surgery in managing diverse presentations of complex spinal stenosis and support stratified analysis to optimize individualized treatment strategies.

Primary Indicators

This study systematically analyzed the improvement in clinical symptoms and imaging outcomes pre- and postsurgery. Before surgery, patients exhibited significant abnormalities in pain intensity, functional impairment, and neurological function. Postoperative follow-up results (Table 2) showed that VAS scores and ODI indices significantly decreased ($p < 0.001$), while JOA scores significantly increased ($p < 0.001$), indicating substantial improvement in clinical symptoms. Additionally, imaging outcomes demonstrated effective alleviation of spinal stenosis. MRI evaluations showed a significant expansion of spinal canal area postoperatively compared to preoperative measurements ($p < 0.001$). Postoperative imaging data revealed no significant recurrence of stenosis or spinal instability, further validating the efficacy and safety of the procedure.

Secondary Indicators

This study also analyzed postoperative complications, recurrence and reoperation rates, and patient satisfaction (Table 3). The overall complication rate was 19.9% (29 cases), including 15 cases (10.3%) of dural tears, 7 cases (4.8%) of nerve injuries, and 7 cases (4.8%) of infections. All complications were promptly managed intraoperatively or postoperatively, and patients gradually recovered without severe long-term sequelae. During follow-up, 14 patients (9.6%) experienced symptom recurrence, with 6 cases (4.1%) requiring reoperation. Recurrence was more frequent in patients with multi-segmental lesions or ligamentum flavum calcification, suggesting a correlation between lesion complexity and recurrence risk. Patient satisfaction scores averaged 4.3 ± 0.7, with 88.4% (129 patients) rating satisfaction at 4 or higher, indicating a high level of approval regarding surgical outcomes and recovery. Patients who achieved significant pain relief (≥50% improvement in VAS scores) generally reported greater satisfaction, while those who experienced complications or recurrence expressed relatively lower satisfaction.

Logistic Regression Analysis of Risk Factors for Postoperative Complications

To further explore the factors associated with the occurrence of postoperative complications, both univariate and multivariate logistic regression analyses were performed. In the univariate analysis (Table 4), ligamentum flavum calcification was significantly associated with postoperative complications (OR = 3.150, 95% CI: 1.357–7.309, $p = 0.008$). None of the other variables, including age, sex, BMI, lesion distribution, lesion segment type, operative time, and blood loss, showed a statistically significant association (all $p > 0.05$).

Table 4. Univariate logistic regression analysis results.

Factors	β value	SE	OR value	95% CI	p
Age	–0.013	0.021	0.987	[0.947, 1.029]	0.549
Sex	0.122	0.427	1.130	[0.489, 2.610]	0.774
BMI (kg/m^2)	–0.034	0.067	0.966	[0.847, 1.102]	0.610
Lesion distribution-cervical	0.214	0.542	1.239	[0.428, 3.586]	0.693
Lesion distribution-thoracic	1.337	1.057	3.806	[0.480, 30.200]	0.206
Lesion distribution-lumbar	–0.053	0.449	0.949	[0.393, 2.288]	0.906
Ligamentum flavum calcification (yes/no)	1.147	0.429	3.150	[1.357, 7.309]	0.008
Single-segment lesion	0.401	0.417	1.493	[0.659, 3.384]	0.337
Multi-segment lesion	–0.401	0.417	0.670	[0.296, 1.517]	0.337
Operative time (minutes)	–0.005	0.006	0.995	[0.984, 1.007]	0.410
Blood loss (mL)	–0.001	0.005	0.999	[0.990, 1.008]	0.775

OR, odds ratio; CI, confidence interval.

Table 5. Multivariate logistic regression analysis results.

Factors	β value	SE	OR value	95% CI	p
Ligamentum flavum calcification	1.228	0.461	3.414	[1.383, 8.432]	0.008

In the multivariate logistic regression analysis (Table 5), after adjusting for potential confounders, ligamentum flavum calcification remained the only independent factor significantly associated with postoperative complications (OR = 3.414, 95% CI: 1.383–8.432, $p = 0.008$).

These results highlighted ligamentum flavum calcification as a key risk factor of postoperative complications. The presence of calcified ligament increases tissue stiffness, compromises visualization under endoscopy, and complicates decompression, thereby elevating the risks of dural tears and incomplete nerve root decompression during UBE procedures. Clinically, this underscores the need for enhanced preoperative imaging assessment and individualized surgical planning in patients with ligamentum flavum calcification.

Discussion

This study evaluated the clinical application of UBE technology in patients with complex spinal stenosis and explored factors associated with postoperative complications. UBE significantly improved pain, functional disability, and neurological function, as demonstrated by marked improvements in VAS, ODI, and JOA scores compared to preoperative values. Imaging evaluations confirmed significant spinal canal expansion. The overall complication rate was 19.9%, with ligamentum flavum calcification identified as an independent risk factor. Patient satisfaction was high, reflecting the favorable efficacy and safety of UBE technology for complex spinal stenosis.

The findings of this study are generally consistent with previous research [18,19], further validating the effectiveness and feasibility of UBE in treating spinal stenosis. UBE employs independent working and viewing channels to achieve precise decompression and real-time visualization, thereby minimizing damage to surrounding neural and vascular structures during surgery [20]. The significant improvements in VAS scores and ODI indices observed in this study are consistent with previous findings in single-segment cases [21]. However, in complex cases, particularly those involving ligamentum flavum calcification or multi-segmental lesions, UBE is associated with increased operative complexity and longer surgical times. Ligamentum flavum calcification increases tissue dissection resistance and the risk of dural tears, which is closely related to tissue hardening caused by fibrosis and calcium salt deposition [22,23]. Moreover, calcified tissue may obscure the surgical field, complicating the procedure and elevating complication risk. Despite these challenges, this study demonstrated relatively low recurrence and reoperation rates in complex cases managed with UBE, most likely attributable to its comprehensive decompression range and enhanced visualization. Compared with conventional surgical methods, UBE maintains lower tissue trauma while achieving superior neural decompression outcomes in complex cases. The results highlight the need for careful preoperative planning, particularly through the integration of advanced imaging guidance and intraoperative navigation technologies to improve surgical precision and safety. Mechanistically, the dual-channel design of UBE facilitates coordination between the endoscope and surgical instruments, reducing tissue damage from repetitive operations compared to traditional single-channel endoscopy [24]. This advantage is especially significant in complex lesions requiring simultaneous removal of ligamentum flavum and neural root decompression. Furthermore, the visualized decompression provided by UBE enables precise handling of pathological adhesions around the nerve roots, thereby reducing the risk of postoperative neurological dysfunction. These mechanisms may explain the high patient satisfaction and low recurrence rates observed in this study.

Despite the valuable data provided by this study, several limitations should be acknowledged. First, as a single-center retrospective study, the external applicability of the findings may be limited. Differences in patient characteristics and surgical practices across centers could affect the generalizability of the results. Second, the relatively short follow-up period focused only on early postoperative outcomes and complications, preventing a comprehensive evaluation of long-term outcomes and potential risks of restenosis. Third, although multivariate logistic regression was used, the limited sample size may have precluded the identification of some potential influencing factors. Finally, imaging evaluations relied mainly on static MRI, lacking dynamic imaging data (e.g., postoperative spinal stability), which may have constrained the assessment of functional recovery.

Future studies should incorporate larger multicenter cohorts with extended follow-up durations to validate both the generalizability and the long-term efficacy of UBE in the treatment of complex spinal stenosis. Particular attention should be paid to recurrence rates, spinal stability, and quality of life over time. Additionally, the integration of intraoperative navigation technologies, 3D imaging assistance, and tools for assessing ligamentum flavum calcification may further optimize preoperative planning and surgical precision. In addition, evaluating the learning curve of UBE and stratifying outcomes based on surgeon experience will be essential for guiding clinical adoption and training.

In summary, UBE demonstrates strong potential as a minimally invasive approach for treating complex spinal stenosis. By refining preoperative evaluation, surgical execution, and postoperative rehabilitation, UBE may serve as a cornerstone in the development of individualized, precision-guided spinal surgery.

Conclusions

UBE significantly improves both clinical symptoms and imaging outcomes in patients with complex spinal stenosis. The procedure maintains low complication and recurrence rates, with ligamentum flavum calcification identified as a key risk factor for postoperative complications. These findings support UBE as a safe and effective minimally invasive surgical option and provide a basis for the development of individualized surgical strategies.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

YN and JX conceived and designed the experiments. HC performed the experiments and did the data analysis. JX provided technical support and critical comments. YN drafted the preliminary manuscript. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study was approved by the ethics committee of Hebei Medical University Third Hospital (Approval No. KS2024-191-1). All procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki. Written informed consent to participate was obtained from all of the participants in the study.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Katz JN, Zimmerman ZE, Mass H, Makhni MC. Diagnosis and Management of Lumbar Spinal Stenosis: A Review. JAMA. 2022; 327: 1688–1699. https://doi.org/10.1001/jama.2022.5921.

[2] Tomkins-Lane C, Melloh M, Lurie J, Smuck M, Battié MC, Freeman B, *et al*. ISSLS Prize Winner: Consensus on the Clinical Diagnosis of Lumbar Spinal Stenosis: Results of an International Delphi Study. Spine. 2016; 41: 1239–1246. https://doi.org/10.1097/BRS.0000000000001476.

[3] Reyes-Sánchez A, García-Ramos CL, Deras-Barrientos CM, Alpizar-Aguirre A, Rosales-Olivarez LM, Pichardo-Bahena R. Ligamentum flavum in lumbar spinal stenosis, disc herniation and degenerative spondylolisthesis. An histopathological description. Acta Ortopedica Mexicana. 2019; 33: 308–313.

[4] Cavazos DR, Schultz R, Higginbotham DO, Vaidya R. Thoracic Spinal Stenosis From Calcified Ligamentum Flavum. Ochsner Journal. 2023; 23: 172–175. https://doi.org/10.31486/toj.23.0003.

[5] Qian J, Liang K, Luo X, Ying C. MRI parameters predict central lumbar spinal stenosis combined with redundant nerve roots: a prospective MRI study. Frontiers in Neurology. 2024; 15: 1385770. https://doi.org/10.3389/fneur.2024.1385770.

[6] Moojen WA, Van der Gaag NA. Minimally invasive surgery for lumbar spinal stenosis. European Journal of Orthopaedic Surgery & Traumatology: Orthopedie Traumatologie. 2016; 26: 681–684. https://doi.org/10.1007/s00590-016-1828-1.

[7] Son SK, Park MK. Unilateral biportal endoscopy for lumbar disc herniation and stenosis. Core Techniques of Minimally Invasive Spine Surgery (pp.131–141). Springer: Singapore. 2023. https://doi.org/10.1007/978-981-19-9849-2_14.

[8] Sellier A, Lechanoine F, Lonjon G, Beucler N, Cam P, Cristini J, *et al*. How to begin unilateral biportal endoscopy (UBE) for segmental lumbar degenerative disease: a step-by-step guide to perfect patient positioning and surgical approach, avoiding common pitfalls. Neurosurgical Review. 2024; 47: 593. https://doi.org/10.1007/s10143-024-02674-9.

[9] Jia D, Qiao X, Wang X, Li S, Li Q, Hao Y, *et al*. Early efficacy observation of the unilateral biportal endoscopic technique in the treatment of multi-level lumbar spinal stenosis. Journal of Orthopaedic Surgery and Research. 2024; 19: 117. https://doi.org/10.1186/s13018-024-04575-5.

[10] Quillo-Olvera J, Quillo-Olvera D, Quillo-Reséndiz J, Barrera-Arreola M. JUBEotSAAoST. The Unilateral Biportal Endoscopic Spine Surgery Concept: An Overview. Unilateral Biportal Endoscopy of the Spine (pp.3–14). Springer: Cham. 2022:3-14. https://doi.org/10.1007/978-3-031-14736-4_1.

[11] Kim SK, Kang SS, Hong YH, Park SW, Lee SC. Clinical comparison of unilateral biportal endoscopic technique versus open microdiscectomy for single-level lumbar discectomy: a multicenter, retrospective analysis. Journal of Orthopaedic Surgery and Research. 2018; 13: 22. https://doi.org/10.1186/s13018-018-0725-1.

[12] Li K, Zhang Z, Ran J, Ma L, Meng X. Unilateral Endoscopic and Unilateral Biportal Endoscopic surgery for lumbar spinal stenosis: a systematic review and meta-analysis. Frontiers in Surgery. 2025; 12: 1585783. https://doi.org/10.3389/fsurg.2025.1585783.

[13] Kim HC, Ko YI, Ko MS, Kim SI, Kim YH. Expanded application of unilateral biportal endoscopy in adult thoracic disease: report of three cases and literature review. European Spine Journal: Official Publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2025; 34: 372–379. https://doi.org/10.1007/s00586-024-08501-5.

[14] Zhang W, Chen Y, Quillo-Olvera J. Biportal Endoscopic Posterior Decompression of Thoracic Spinal Stenosis Due to Ossification of Ligamentum Flavum. Unilateral Biportal Endoscopy of the Spine: An Atlas of Surgical Techniques (pp.507–520). Springer: Cham. 2022. https://doi.org/10.1007/978-3-031-14736-4_28.

[15] Cook CE, Garcia AN, Wright A, Shaffrey C, Gottfried O. Measurement Properties of the Oswestry Disability Index in Recipients of Lumbar Spine Surgery. Spine. 2021; 46: E118–E125. https://doi.org/10.1097/BRS.0000000000003732.

[16] Pao JL. Preliminary Clinical and Radiological Outcomes of the "No-Punch" Decompression Techniques for Unilateral Biportal Endoscopic Spine Surgery. Neurospine. 2024; 21: 732–741. https://doi.org/10.14245/ns.2448376.188.

[17] Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods. 2007; 39: 175–191. https://doi.org/10.3758/bf03193146.

[18] Tan B, Yang QY, Fan B, Xiong C. Decompression *via* unilateral biportal endoscopy for severe degenerative lumbar spinal stenosis: A comparative study with decompression *via* open discectomy. Frontiers in Neurology. 2023; 14: 1132698. https://doi.org/10.3389/fneur.2023.1132698.

[19] Hu Y, Fu H, Yang D, Xu W. Clinical efficacy and imaging outcomes of unilateral biportal endoscopy with unilateral laminotomy for bilateral decompression in the treatment of severe lumbar spinal stenosis. Frontiers in Surgery. 2023; 9: 1061566. https://doi.org/10.3389/fsurg.2022.1061566.

[20] Nava-Dimaano HD. Put it into practice: the unilateral biportal endoscopic surgery. Unilateral Biportal Endoscopy of the Spine: An Atlas of Surgical Techniques (pp.149–181). Springer: Cham. 2022. https://doi.org/10.1007/978-3-031-14736-4_12.

[21] Zhou Y, Chen R, Yu K, Liao Z. Comparison of the efficacy of unilateral biportal endoscopic transforaminal lumbar interbody fusion (UBETLIF) versus minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) in the treatment of singlesegment degenerative lumbar spinal stenosis. Orthopaedic Biomechanics Materials and Clinical Study. 2024; 21: 32–37. (In Chinese)

[22] Nishikawa M, Yoshimura M, Naito K, Yamagata T, Goto H, Hara M, *et al*. The Symptomatic Calcification and Ossification of the Ligamentum Flavum in the Spine: Our Experience and Review of the Literature. Journal of Clinical Medicine. 2023; 13: 105. https://doi.org/10.3390/jcm13010105.

[23] Zhao Y, Xiang Q, Jiang S, Lin J, Wang L, Sun C, *et al*. Incidence and risk factors of dural ossification in patients with thoracic ossification of the ligamentum flavum. Journal of Neurosurgery. Spine. 2022; 38: 131–138. https://doi.org/10.3171/2022.7.SPINE22645.

[24] Liu L, Zhang X, Kang N. Application status and considerations of unilateral biportal endoscopy technique. Chinese Journal of Reparative and Reconstructive Surgery. 2024; 38: 1510–1516. https://doi.org/10.7507/1002-1892.202408050. (In Chinese)