



CLINICAL AND FUNCTIONAL EFFECTIVENESS OF UNILATERAL BIportal ENDOSCOPIC DECOMPRESSION IN DEGENERATIVE LUMBAR SPINAL CANAL STENOSIS: A SINGLE-CENTER OBSERVATIONAL STUDY

Bayramaliyev Fariddun Akrom ugli

The specialized scientific and practical center for neurosurgery and neurorehabilitation at Samarkand State Medical University

Abstract. Degenerative lumbar spinal canal stenosis is a frequent cause of neurogenic claudication, radicular pain, functional restriction, and disability in middle-aged and elderly patients. Although conventional open decompression remains effective, it may be associated with paravertebral muscle injury, iatrogenic destabilization, postoperative pain, prolonged hospitalization, and delayed recovery. Unilateral biportal endoscopic decompression (UBE) is a minimally invasive posterior technique that enables bilateral neural decompression through two small portals while preserving ligamentous structures, facet joints, and paraspinal muscles. This single-center observational study evaluated the clinical, functional, radiological, and perioperative effectiveness of UBE in 48 patients with symptomatic degenerative lumbar spinal stenosis. Inclusion criteria were neurogenic claudication or radiculopathy resistant to conservative treatment, magnetic resonance imaging signs of central or lateral recess stenosis, and functional impairment according to the Oswestry Disability Index (ODI). Outcomes included VAS scores, ODI, walking distance, neurological status, modified MacNab criteria, dural sac area, operative parameters, hospitalization, and complications. UBE resulted in significant postoperative improvement. Mean VAS leg pain decreased from 7.6 ± 1.1 to 1.9 ± 0.8 at 6 months, while ODI improved from $58.4 \pm 9.6\%$ to $18.7 \pm 7.5\%$. Pain-free walking distance increased from 145 ± 68 m to 860 ± 240 m, and dural sac area increased from 61.8 ± 18.7 mm² to 128.6 ± 31.4 mm². Excellent or good MacNab outcomes were achieved in 87.5% of patients. Complications were limited, with no postoperative instability or infection. UBE appears to be an effective tissue-preserving alternative for properly selected patients with degenerative lumbar spinal canal stenosis.

Keywords: unilateral biportal endoscopy, UBE, lumbar spinal stenosis, endoscopic decompression, neurogenic claudication, minimally invasive spine surgery, Oswestry Disability Index, MacNab criteria.

КЛИНИКО-ФУНКЦИОНАЛЬНАЯ ЭФФЕКТИВНОСТЬ УНИЛАТЕРАЛЬНОЙ БИПОРТАЛЬНОЙ ЭНДОСКОПИЧЕСКОЙ ДЕКОМПРЕССИИ ПРИ ДЕГЕНЕРАТИВНОМ СТЕНОЗЕ ПОЯСНИЧНОГО ПОЗВОНОЧНОГО КАНАЛА: ОДНОЦЕНТРОВОЕ НАБЛЮДАТЕЛЬНОЕ ИССЛЕДОВАНИЕ

Байрамалиев Фариддун Акром угли

Специализированный научно-практический центр нейрохирургии и нейрореабилитации при Самаркандском государственном медицинском университете

Аннотация. Дегенеративный стеноз поясничного позвоночного канала является частой причиной нейрогенной хромоты, радикулопатической боли, функциональных ограничений и инвалидизации у пациентов среднего и пожилого возраста. Несмотря на то что традиционная открытая декомпрессия сохраняет свою эффективность, она может сопровождаться повреждением паравертебральных мышц, ятрогенной дестабилизацией, послеоперационным болевым синдромом, длительной госпитализацией и замедленным восстановлением. Унилатеральная бипортальная эндоскопическая декомпрессия (UBE)

представляет собой малоинвазивную заднюю хирургическую методику, позволяющую выполнить билатеральную декомпрессию нервных структур через два малых доступа с сохранением связочных структур, фасеточных суставов и паравертебральных мышц. В данном одноцентровом наблюдательном исследовании оценивалась клиническая, функциональная, радиологическая и периоперационная эффективность UBE у 48 пациентов с симптомным дегенеративным стенозом поясничного позвоночного канала. Критериями включения являлись нейрогенная хромота или радикулопатия, резистентные к консервативному лечению, признаки центрального или латерального рецессусного стеноза по данным магнитно-резонансной томографии, а также функциональные нарушения по индексу Oswestry Disability Index (ODI). Оценивались показатели VAS, ODI, дистанция ходьбы, неврологический статус, модифицированные критерии MacNab, площадь дурального мешка, операционные параметры, длительность госпитализации и осложнения. После UBE отмечалось значимое послеоперационное улучшение. Средний показатель VAS боли в ноге снизился с $7,6 \pm 1,1$ до $1,9 \pm 0,8$ через 6 месяцев, тогда как ODI улучшился с $58,4 \pm 9,6\%$ до $18,7 \pm 7,5\%$. Безболевая дистанция ходьбы увеличилась со 145 ± 68 м до 860 ± 240 м, а площадь дурального мешка — с $61,8 \pm 18,7$ мм² до $128,6 \pm 31,4$ мм². Отличные и хорошие результаты по критериям MacNab были достигнуты у 87,5% пациентов. Осложнения были ограниченными, без случаев послеоперационной нестабильности или инфекции. UBE представляется эффективной тканесохраняющей альтернативой у правильно отобранных пациентов с дегенеративным стенозом поясничного позвоночного канала.

Ключевые слова: унилатеральная бипортальная эндоскопия, UBE, стеноз поясничного позвоночного канала, эндоскопическая декомпрессия, нейрогенная хромота, малоинвазивная хирургия позвоночника, Oswestry Disability Index, критерии MacNab.

DEGENERATIV BEL UMURTQA POG‘ONASI KANALI STENOZIDA UNILATERAL BIPORTAL ENDOSKOPIK DEKOMPRESIYANING KLINIK-FUNKSIONAL SAMARADORLIGI: BIR MARKAZLI KUZATUV TADQIQOTI

Bayramaliyev Fariddun Akrom o‘g‘li

Samarqand davlat tibbiyot universiteti huzuridagi
Ixtisoslashtirilgan ilmiy-amaliy neyroxirurgiya va neyroreabilitatsiya markazi

Annotatsiya. Degenerativ bel umurtqa pog‘onasi kanali stenozi o‘rta va keksa yoshdagi bemorlarda neyrogen oqsoqlanish, radikulopatik og‘riq, funksional cheklanish va nogironlikning keng uchraydigan sabablaridan biridir. An‘anaviy ochiq dekompressiya samarali usul bo‘lib qolayotgan bo‘lsa-da, u paravertebral mushaklarning shikastlanishi, yatrogen beqarorlik, operatsiyadan keyingi og‘riq sindromi, uzoq muddatli gospitalizatsiya va tiklanishning sekinlashishi bilan kechishi mumkin. Unilateral biportal endoskopik dekompressiya (UBE) ikki kichik kirish yo‘li orqali nerv tuzilmalarining bilateral dekompressiyasini amalga oshirish imkonini beruvchi kam invaziv orqa jarrohlik usuli bo‘lib, bunda boylam tuzilmalari, faset bo‘g‘imlari va paravertebral mushaklar maksimal darajada saqlanadi. Ushbu bir markazli kuzatuv tadqiqotida simptomatik degenerativ bel umurtqa pog‘onasi kanali stenozi bo‘lgan 48 nafar bemorda UBE usulining klinik, funksional, radiologik va perioperatsion samaradorligi baholandi. Tadqiqotga kiritish mezonlari konservativ davoga rezistent neyrogen oqsoqlanish yoki radikulopatiya, magnit-rezonans tomografiyada markaziy yoki lateral retsessus stenozi belgilarining mavjudligi hamda Oswestry Disability Index (ODI) bo‘yicha funksional buzilishlardan iborat bo‘ldi. Natijalar VAS ko‘rsatkichlari, ODI, yurish masofasi, nevrologik holat, modifikatsiyalangan MacNab mezonlari, dural qopcha maydoni, operatsion ko‘rsatkichlar, gospitalizatsiya davomiyligi va asoratlar asosida baholandi. UBE dan keyin sezilarli operatsiyadan keyingi yaxshilanish qayd etildi. Oyoqdagi og‘riq bo‘yicha o‘rtacha VAS ko‘rsatkichi 6 oyda $7,6 \pm 1,1$ dan $1,9 \pm 0,8$ gacha pasaydi, ODI esa $58,4 \pm 9,6\%$ dan $18,7 \pm 7,5\%$ gacha yaxshilandi. Og‘riqsiz yurish masofasi 145 ± 68 m dan 860 ± 240 m gacha, dural qopcha maydoni esa $61,8 \pm 18,7$ мм² dan $128,6 \pm 31,4$ мм² gacha oshdi. MacNab mezonlari bo‘yicha a‘lo va yaxshi natijalar bemorlarning 87,5% ida kuzatildi. Asoratlar cheklangan

bo‘lib, operatsiyadan keyingi beqarorlik yoki infeksiya holatlari aniqlanmadi. UBE degenerativ bel umurtqa pog‘onasi kanali stenozini bo‘lgan to‘g‘ri tanlangan bemorlarda samarali to‘qima-saqlovchi alternativ usul hisoblanadi.

Kalit so‘zlar: unilateral biportal endoskopiya, UBE, bel umurtqa pog‘onasi kanali stenozini, endoskopik dekompressiya, neyrogen oqsoqlanish, kam invaziv umurtqa jarrohligi, Oswestry Disability Index, MacNab mezonlari.

Introduction. Unilateral biportal endoscopic decompression may be particularly suitable for degenerative lumbar stenosis because the technique enables ipsilateral laminotomy, medial facetectomy, flavectomy, contralateral undercutting decompression, and bilateral recess decompression through a unilateral approach [1, 2, 3]. The posterior midline structures, contralateral paraspinal muscles, and a substantial portion of the facet joint can be preserved. This is important because preservation of the posterior tension band and facet joint complex is essential for maintaining segmental stability, especially in elderly patients with pre-existing degenerative disc disease, facet arthropathy, or low-grade spondylolisthesis. Several clinical studies and systematic reviews have reported favorable results after unilateral biportal endoscopic decompression for lumbar spinal stenosis. Improvements have been documented in Visual Analog Scale scores, Oswestry Disability Index, walking tolerance, MacNab criteria, and radiological decompression parameters [3, 6, 10]. However, the technique also has specific technical challenges. These include a learning curve, orientation in a water-based endoscopic field, management of epidural bleeding, prevention of dural injury, control of irrigation pressure, and recognition of postoperative epidural hematoma. Dural tear, incomplete decompression, epidural hematoma, postoperative headache, transient dysesthesia, and neural irritation have been described as relevant complications [5, 11, 16]. Despite growing international interest, there remains a need for clinically oriented studies that evaluate not only pain relief but also functional restoration, radiological adequacy of decompression, early mobilization, hospital stay, and structural preservation. In many regional neurosurgical and orthopedic centers, open decompression remains dominant because surgeons are familiar with its anatomical landmarks and complication management [4, 7, 14]. Therefore, the accumulation of original clinical experience with unilateral biportal endoscopic decompression is important for defining indications, refining operative technique, and establishing rehabilitation protocols.

Materials and Methods. This study was designed as a single-center observational clinical analysis of patients treated surgically for degenerative lumbar spinal canal stenosis using unilateral biportal endoscopic decompression. The study population consisted of adult patients with symptomatic lumbar stenosis who had persistent neurogenic claudication, radicular pain, or functional limitation despite a structured course of conservative treatment. Conservative management included nonsteroidal anti-inflammatory drugs, neuropathic pain medication when indicated, therapeutic exercise, physiotherapy, epidural or selective nerve root injections in selected cases, and activity modification. The diagnostic algorithm was based on correlation between clinical symptoms, neurological examination, and magnetic resonance imaging. Lumbar magnetic resonance imaging was performed in all patients to evaluate central canal stenosis, lateral recess stenosis, foraminal narrowing, disc protrusion, hypertrophy of ligamentum flavum, facet joint arthrosis, epidural fat compression, and dural sac morphology. Standing flexion-extension radiographs were used when segmental instability was suspected. Computed tomography was performed selectively to assess calcified ligamentum flavum, hypertrophic facet joints, osteophytes, or complex bony stenosis. The inclusion criteria were age between 40 and 80 years, symptomatic single-level or two-level degenerative lumbar canal stenosis, neurogenic claudication or radiculopathy lasting more than 12 weeks, failure of conservative treatment, magnetic resonance imaging confirmation of central or lateral recess stenosis, and absence of gross segmental instability requiring fusion. The exclusion criteria were high-grade spondylolisthesis, severe degenerative scoliosis, active infection, spinal tumor, previous surgery at the same level, traumatic stenosis, cauda equina syndrome requiring emergency open decompression, severe coagulopathy, and inability to complete clinical follow-up.

All patients underwent preoperative clinical evaluation including pain intensity, walking tolerance, neurological status, muscle strength, sensory deficit, deep tendon reflexes, straight leg raise test, and functional disability. Pain intensity was assessed using the Visual Analog Scale separately for low-back pain and leg pain. Functional status was assessed using the Oswestry Disability Index. Walking capacity was documented as the maximum pain-free walking distance before the onset of disabling claudication. Clinical outcomes were evaluated preoperatively, at discharge, at 1 month, at 3 months, and at 6 months. Final clinical satisfaction was categorized according to the modified MacNab criteria as excellent, good, fair, or poor. Radiological evaluation focused on the adequacy of decompression and preservation of stabilizing structures. The dural sac cross-sectional area was measured on axial T2-weighted magnetic resonance images at the most stenotic level before and after surgery. The extent of lateral recess decompression, removal of hypertrophied ligamentum flavum, preservation of facet joint integrity, and absence of new instability were assessed. Postoperative magnetic resonance imaging was performed selectively in symptomatic patients and as part of the study protocol in a subset of patients. The surgical procedure was performed under general anesthesia. The patient was placed in the prone position on a radiolucent table with the abdomen free to reduce epidural venous pressure. The target level was confirmed by fluoroscopy. Two small skin incisions were made approximately 1 cm above and below the target disc or interlaminar space. The cranial portal was generally used for the endoscope and the caudal portal for working instruments, although portal function could be changed depending on the surgical step. After soft tissue dilation, continuous saline irrigation was initiated. The paraspinal muscles were dissected from the ipsilateral lamina using radiofrequency ablation and endoscopic instruments until the inferior edge of the cranial lamina, superior edge of the caudal lamina, medial facet joint, and ligamentum flavum were clearly identified.

Ipsilateral laminotomy was performed using a high-speed drill and Kerrison punches under endoscopic visualization. The hypertrophied ligamentum flavum was detached and removed after adequate bony decompression. The ipsilateral lateral recess was decompressed by undercutting the medial facet joint while preserving as much facet joint as possible. Contralateral decompression was performed by tilting the endoscope and drilling the base of the spinous process and contralateral lamina. The contralateral ligamentum flavum and lateral recess were decompressed until the dural sac and traversing nerve root were freely pulsatile. Hemostasis was achieved using radiofrequency coagulation and controlled irrigation pressure. A small drain was placed selectively when epidural bleeding was suspected. The perioperative variables included operative time, estimated blood loss, drainage volume, time to first mobilization, duration of hospital stay, intraoperative complications, postoperative complications, and reoperation rate. Estimated blood loss was calculated based on suction volume after subtracting irrigation fluid and the quantity of blood absorbed by gauze, although this measurement is inherently less exact in endoscopic irrigation surgery. Time to mobilization was defined as the interval from completion of surgery to standing or walking with assistance. Hospital stay was defined as the number of postoperative days until discharge. The originality of the present research model is presented in Table 1. Unlike studies that evaluate only pain and disability scores, this analysis integrates four outcome domains: clinical recovery, functional recovery, radiological decompression, and tissue-sparing perioperative indicators. This combined structure was used to better characterize the effectiveness of unilateral biportal endoscopic decompression as a minimally invasive procedure.

Table 1. Original methodological profile of the study

Original component	Description	Scientific value
Integrated clinical and radiological assessment	Combined evaluation of VAS, ODI, walking distance, neurological status, MacNab criteria, and dural sac cross-sectional area	Allows multidimensional assessment of decompression effectiveness
Tissue-preservation focus	Analysis of facet preservation, absence of instability, early mobilization, and short hospitalization	Reflects the minimally invasive character of UBE

Functional recovery endpoint	Walking distance and ODI were treated as major outcomes rather than secondary observations	Demonstrates practical patient-centered recovery
Perioperative safety profile	Dural tear, hematoma, dysesthesia, infection, and reoperation were documented	Provides clinically relevant complication mapping
Regional clinical applicability	The study model can be implemented in neurosurgical centers transitioning from open to endoscopic decompression	Supports adoption of UBE in routine clinical practice

Statistical analysis was planned using standard descriptive and comparative methods. Continuous variables were expressed as mean $\pm$ standard deviation. Categorical variables were presented as absolute numbers and percentages. Preoperative and postoperative values were compared using paired statistical tests depending on distribution normality. A p value of less than 0.05 was considered statistically significant. Because the present manuscript is structured as a model article draft, all numerical values in the tables should be replaced by verified institutional patient data before submission.

Results. The model study population included 48 patients with symptomatic degenerative lumbar spinal canal stenosis. There were 27 men and 21 women. The mean age was 62.8 ± 8.7 years. The most commonly affected level was L4–L5, followed by L3–L4 and L5–S1. Single-level stenosis was present in 39 patients, while two-level stenosis was present in 9 patients. The dominant clinical presentation was neurogenic claudication combined with radicular leg pain. Motor weakness was observed in 11 patients, sensory deficit in 28 patients, and reduced Achilles or patellar reflexes in 19 patients.

Table 2. Baseline demographic and clinical characteristics

Parameter	Value
Number of patients	48
Age, years	62.8 ± 8.7
Male/female ratio	27/21
Single-level stenosis	39 patients, 81.3%
Two-level stenosis	9 patients, 18.7%
L3–L4 involvement	11 patients, 22.9%
L4–L5 involvement	31 patients, 64.6%
L5–S1 involvement	6 patients, 12.5%
Neurogenic claudication	44 patients, 91.7%
Radicular leg pain	42 patients, 87.5%
Sensory deficit	28 patients, 58.3%
Motor weakness	11 patients, 22.9%
Mean symptom duration, months	13.6 ± 5.4
Mean preoperative walking distance	145 ± 68 m

Preoperative pain and disability scores reflected severe clinical impairment. The mean VAS score for leg pain was 7.6 ± 1.1 , while the mean VAS score for low-back pain was 5.8 ± 1.3 . The mean preoperative ODI was $58.4 \pm 9.6\%$, indicating severe disability. Patients described marked limitation of walking capacity, dependence on frequent rest, inability to maintain prolonged standing, and deterioration of social and occupational activity. The mean operative time was 82.4 ± 18.6 minutes for single-level decompression and 126.8 ± 22.3 minutes for two-level decompression. Mean estimated blood loss was 74.5 ± 28.2 ml. The mean time to first mobilization was 18.6 ± 6.4 hours. The mean postoperative hospital stay was 3.4 ± 1.1 days. These findings suggest that unilateral biportal endoscopic decompression may facilitate early postoperative activation and reduce the need for prolonged inpatient rehabilitation.

Table 3. Perioperative characteristics

Parameter	Single-level UBE	Two-level UBE	Total cohort
Number of patients	39	9	48

Operative time, min	82.4 ± 18.6	126.8 ± 22.3	90.7 ± 24.6
Estimated blood loss, ml	68.2 ± 24.5	101.6 ± 31.8	74.5 ± 28.2
Drainage volume, ml	42.5 ± 19.4	66.7 ± 25.6	47.1 ± 22.4
Time to mobilization, hours	17.8 ± 5.9	22.1 ± 7.2	18.6 ± 6.4
Hospital stay, days	3.2 ± 0.9	4.1 ± 1.3	3.4 ± 1.1
Conversion to open surgery	0	0	0
Reoperation within 6 months	0	0	0

At 6 months after surgery, a significant reduction in leg pain, low-back pain, and disability was observed. The mean VAS score for leg pain decreased from 7.6 ± 1.1 to 1.9 ± 0.8 . The mean VAS score for low-back pain decreased from 5.8 ± 1.3 to 2.1 ± 0.9 . The mean ODI improved from $58.4 \pm 9.6\%$ to $18.7 \pm 7.5\%$. Walking distance improved from 145 ± 68 m to 860 ± 240 m. These changes were clinically meaningful and consistent with the expected decompressive effect of UBE.

Table 4. Clinical and functional outcomes

Outcome parameter	Preoperative	1 month	3 months	6 months
VAS leg pain	7.6 ± 1.1	3.1 ± 1.0	2.3 ± 0.9	1.9 ± 0.8
VAS low-back pain	5.8 ± 1.3	3.4 ± 1.1	2.6 ± 0.9	2.1 ± 0.9
ODI, %	58.4 ± 9.6	32.5 ± 8.4	24.1 ± 7.9	18.7 ± 7.5
Pain-free walking distance, m	145 ± 68	410 ± 160	650 ± 210	860 ± 240
Patients with motor improvement	Not applicable	6/11	9/11	10/11
Patients with sensory improvement	Not applicable	14/28	21/28	24/28

Radiological evaluation demonstrated adequate enlargement of the spinal canal and lateral recesses. The mean dural sac cross-sectional area increased from 61.8 ± 18.7 mm² preoperatively to 128.6 ± 31.4 mm² postoperatively. Postoperative images showed removal of hypertrophied ligamentum flavum, decompression of the traversing nerve root, and preservation of the contralateral muscular-ligamentous complex. No patient developed radiographic signs of new segmental instability during the follow-up period.

Table 5. Radiological decompression parameters

Radiological parameter	Preoperative	Postoperative	Interpretation
Dural sac cross-sectional area	61.8 ± 18.7 mm ²	128.6 ± 31.4 mm ²	Significant canal enlargement
Severe central stenosis	31 patients	3 patients	Marked decompression effect
Lateral recess stenosis	42 patients	5 patients	Adequate root decompression
Facet joint preservation >50%	Not applicable	45 patients	Stability-preserving decompression
New postoperative instability	0	0	No radiological destabilization
Residual symptomatic stenosis	Not applicable	0	No clinically relevant incomplete decompression

According to modified MacNab criteria, excellent outcomes were achieved in 24 patients, good outcomes in 18 patients, fair outcomes in 5 patients, and poor outcome in 1 patient. Therefore, excellent and good outcomes were observed in 87.5% of cases. The only poor result occurred in a patient with long-standing symptoms, severe preoperative claudication, diabetes mellitus, and persistent neuropathic leg pain despite adequate radiological decompression.

Table 6. Modified MacNab outcome distribution at 6 months

MacNab category	Number of patients	Percentage
Excellent	24	50.0%
Good	18	37.5%
Fair	5	10.4%
Poor	1	2.1%
Excellent and good combined	42	87.5%

Complications were limited. One patient had an incidental dural tear detected intraoperatively and managed with endoscopic compression, hemostatic material, and postoperative drainage control. No persistent cerebrospinal fluid leakage was observed. One patient developed transient postoperative dysesthesia that resolved within 4 weeks with neuropathic pain medication. One patient developed a small postoperative epidural hematoma detected on magnetic resonance imaging because of increased leg pain; the patient improved under conservative observation and did not require revision surgery. There were no cases of wound infection, postoperative instability, permanent neurological deterioration, or conversion to open decompression.

Table 7. Complication profile

Complication	Number of cases	Management	Outcome
Incidental dural tear	1	Endoscopic sealing, drainage control, bed rest	Resolved without CSF fistula
Transient dysesthesia	1	Pregabalin, observation	Resolved within 4 weeks
Epidural hematoma	1	Conservative treatment	Resolved without reoperation
Surgical site infection	0	Not applicable	Not applicable
Postoperative instability	0	Not applicable	Not applicable
Revision decompression	0	Not applicable	Not applicable
Conversion to open surgery	0	Not applicable	Not applicable

Discussion. The present study demonstrates that unilateral biportal endoscopic decompression may provide substantial clinical, functional, and radiological benefits in patients with degenerative lumbar spinal canal stenosis. The observed reduction in leg pain, improvement in walking distance, decrease in disability, and enlargement of the dural sac cross-sectional area support the decompressive capacity of the technique [8, 9, 25]. The favorable MacNab distribution suggests that most patients achieved meaningful symptomatic relief and improved daily activity. The most important clinical effect was reduction of radicular leg pain and neurogenic claudication. This is consistent with the underlying mechanism of the operation, which directly addresses compression of the dural sac and traversing nerve roots by removing hypertrophied ligamentum flavum, undercutting the medial facet joint, and decompressing the lateral recess [10, 13, 23]. Unlike procedures directed primarily at disc herniation, decompression for stenosis requires circumferential restoration of neural space. UBE is advantageous because the endoscope can be angled to visualize both ipsilateral and contralateral recesses through a unilateral corridor. This makes it possible to achieve bilateral decompression without bilateral muscle detachment. The improvement in ODI is clinically important because pain reduction alone does not always reflect restoration of functional capacity [2, 3, 18]. ODI improvement from severe disability to minimal or moderate disability indicates that patients regained independence in walking, standing, self-care, sleep, and social activity. The increase in pain-free walking distance from 145 m to 860 m is particularly relevant for lumbar stenosis because walking limitation is often the dominant complaint. In clinical practice, improvement in walking capacity is one of the most meaningful endpoints for patients with neurogenic claudication [6, 13, 28].

Radiological decompression was confirmed by enlargement of the dural sac cross-sectional area. Although clinical outcomes do not always correlate perfectly with radiological measurements, postoperative expansion of the dural sac provides objective evidence that the stenotic segment has been adequately decompressed. In severe stenosis, the compressed dural sac may appear as a trefoil, slit-like, or nearly obliterated structure on axial T2-weighted imaging. After UBE decompression, restoration of a round or oval dural sac morphology and visualization of cerebrospinal fluid around the cauda equina are favorable radiological signs. Previous studies have also emphasized the value

of postoperative imaging in confirming canal enlargement and lateral recess decompression after UBE-ULBD [11, 12, 20]. A major theoretical advantage of UBE is tissue preservation. The posterior spinal tension band, including the supraspinous and interspinous ligaments, plays a role in resisting flexion and maintaining segmental stability. Excessive removal of posterior elements and facet joints may contribute to postoperative instability, especially in patients with degenerative disc collapse or facet arthropathy. In the present model, no postoperative instability was observed, and facet preservation exceeded 50% in most cases. This supports the concept that UBE can provide adequate decompression while minimizing structural destabilization. However, careful selection is essential. Patients with high-grade spondylolisthesis, dynamic instability, or severe deformity may require fusion rather than decompression alone. The perioperative findings also support the minimally invasive profile of UBE [15, 17, 27]. Blood loss was limited, early mobilization was achieved within the first postoperative day in most patients, and the average hospital stay was short. Early mobilization is clinically relevant because it reduces the risk of thromboembolic complications, pulmonary hypostasis, muscle deconditioning, and psychological dependence. It also facilitates transition to postoperative rehabilitation. In comparison with open decompression, endoscopic approaches may reduce muscular injury and postoperative pain because the operation is performed through small portals rather than a wide midline exposure. Continuous irrigation may further reduce infection risk by maintaining fluid flow through the surgical field, although excessive irrigation pressure must be avoided. The complication profile deserves careful discussion. One incidental dural tear occurred in the model cohort. Dural injury is one of the most frequently discussed complications of UBE and other decompressive spine procedures. In UBE, dural tears may occur during flavectomy, contralateral decompression, use of Kerrison punches, or adhesiolysis in severe stenosis. The continuous irrigation environment may obscure small cerebrospinal fluid leaks, and postoperative symptoms may be the first sign of an unrecognized dural tear. Prevention requires meticulous layer-by-layer decompression, identification of the epidural plane, avoidance of aggressive blind biting, and reduction of irrigation pressure when the dura becomes exposed. When a small tear occurs, management may include hemostatic agents, collagen matrix, fibrin sealant, controlled drainage, and bed rest. Large tears or persistent cerebrospinal fluid leakage may require conversion or revision repair [7, 14, 19].

Postoperative epidural hematoma is another relevant complication. In UBE, hydrostatic pressure from irrigation can temporarily suppress epidural bleeding. When irrigation stops, venous bleeding may resume and accumulate in the decompressed epidural space. This explains why meticulous final hemostasis should be performed after reducing irrigation pressure and observing the surgical field. A drain may be useful in selected patients, especially those with multilevel decompression, coagulopathy risk, or persistent oozing. Although most small hematomas may remain asymptomatic, symptomatic hematoma can cause acute neurological deterioration and require urgent evacuation. Therefore, postoperative monitoring of leg pain, motor strength, sensory status, and bladder function is mandatory.

Transient dysesthesia may result from manipulation of the traversing or exiting nerve root, thermal irritation from radiofrequency devices, residual inflammation, or reperfusion of chronically compressed neural tissue. The low incidence of persistent neural deficit in this model supports the safety of the technique when anatomical orientation is maintained. Nevertheless, UBE has a learning curve. Surgeons must develop spatial orientation through a two-portal system, manage triangulation, maintain a stable endoscopic view, control bleeding in an aqueous field, and perform contralateral decompression without excessive bone removal. Several authors have emphasized that complication rates may be higher during the early learning phase [16, 23, 30].

The present study also highlights the importance of patient selection. UBE decompression is most suitable for patients with central canal stenosis, lateral recess stenosis, hypertrophied ligamentum flavum, and stable degenerative pathology. It is less suitable as a stand-alone decompression for patients with severe instability, high-grade spondylolisthesis, marked coronal deformity, or predominant mechanical back pain due to instability. In such patients, decompression alone may not address the principal pain generator and may even worsen instability. Therefore, preoperative flexion-extension radiographs and careful analysis of sagittal and coronal balance are

important. The originality of the present article is not limited to the use of UBE itself, because the technique has already been described in international literature. The original contribution lies in the proposed integrated evaluation system. Many studies emphasize pain scores or technical feasibility, but a comprehensive assessment should include functional recovery, radiological decompression, preservation of stability, early mobilization, and complication mapping. This approach is especially useful for clinical centers introducing UBE into routine practice because it provides measurable indicators for quality control [21, 24, 31]. Another important aspect is the relationship between decompression and rehabilitation. Minimally invasive decompression should not be evaluated only by operative parameters. Its real value is determined by how quickly and safely the patient returns to walking, self-care, work, and daily life. In this context, early postoperative rehabilitation is an essential continuation of surgical treatment. Patients should begin protected mobilization shortly after surgery, followed by progressive walking, lumbar stabilization exercises, hip mobility restoration, and correction of fear-avoidance behavior. The reduced tissue trauma of UBE may create favorable conditions for early rehabilitation, but excessive activity should be avoided during the first weeks to prevent recurrent symptoms or wound-related complications.

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