Article

Comparison of Percutaneous Transforaminal Endoscopic Decompression and Full Endoscopic Lamina Fenestration Decompression in the Treatment of Degenerative Lumbar Spinal Stenosis with Unilateral Radicular Pain: A Retrospective Study

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Background: Endoscopic decompression of the spinal canal is an emerging procedure for the treatment of degenerative lumbar spinal stenosis, but there are few reports of comparative studies of endoscopic techniques for transforaminal and non-transforaminal approaches.
Objective: To compare the clinical application of percutaneous transforaminal endoscopic decompression (PTED) and full endoscopic lamina fenestration decompression (Endo-LOVE) for treating degenerative lumbar spinal stenosis with unilateral radicular pain.
Methods: A total of 58 patients with degenerative lumbar spinal stenosis (DLSS) with unilateral radicular pain in the lower extremities who underwent endoscopic decompression treatment from June 2020 to December 2021 were retrospectively identified and divided into two groups (PTED vs Endo-LOVE). The two groups' perioperative data were analyzed according to surgical modalities. The Visual Analogue Score (VAS) for pain, Oswestry Disability Index (ODI), modified MacNab criteria, and dural sac cross-sectional area (DSCSA) were used to assess the post-operative outcomes of the two groups.
Results: All 58 patients completed the operation and received more than 12 months of follow-up. There was no significant difference in the operation time, number of intraoperative fluoroscopies, intraoperative bleeding, or postoperative hospitalization time between the two groups ($p > 0.05$); VAS scores and ODIs of the two groups at all postoperative time points were significantly lower than before the operation ($p < 0.05$), and there was no significant difference in the comparison of the clinical efficacy between the two groups ($p > 0.05$); the DSCSA of the two groups at the last postoperative follow-up was significantly larger than before the operation ($p < 0.05$), and there was no significant difference in the improvement of DSCSA between them ($p > 0.05$).
Conclusions: Both procedures are safe and effective in the treatment of DLSS with unilateral lower extremity radicular pain, and we should be specific about the choice of spinal stenosis treatment.

Keywords: degenerative lumbar spinal stenosis; full visualizational endoscope; transforaminal approach; lamina fenestration; clinical application

Introduction

Degenerative lumbar spinal stenosis (DLSS) is one of the common causes of neurogenic claudication in the elderly population. DLSS is facilitated by neural ischemia and reflux caused by reduced volume at single or multiple spinal canal levels, manifesting in several clinical symptoms. Surgery is often required when conservative treatment fails intervention [1]. Traditionally, posterior spinal decompression combined with interbody implant fusion has been considered the gold standard for the treatment of DLSS; however, the risks of an aging population, complex comorbidities, surgical trauma, accelerated degeneration of adjacent joints, and failure of fusion and internal fixation should not be ignored [2, 3]. Lumbar spine degeneration has gained greater prominence following the COVID-19 epidemic, as economic constraints become more pronounced, the benefits of minimally invasive surgical approaches are better recognized [4]. The advent of minimally invasive spinal therapies has brought endoscopic non-fusion decompression to the forefront of accelerated rehabilitation surgery. This approach aligns with the goal of reducing trauma, preserving paravertebral stabilizing musculature and small joints, and minimizing post-operative downtime. Of this surgery type, percutaneous transforaminal endoscopic decompression (PTED) is widely used in treating lumbar disc herniation, lateral recess, or foraminal stenosis, where its efficacy is satisfactory [5]. However, the central canal lesion, severe foraminal stenosis, wide transverse processes, and high iliac crest obstruction may interfere with treating lumbar disc herniation and foraminal stenosis. Crest occlusion and other disruptions can pose challenges when utilizing the lateral approach for PTED. Full endoscopic lamina fenestration discectomy (Endo-LOVE) [6] compensates for the technical blind spot of PTED, allowing for closer surgical access comparable to traditional posterior open lumbar spine surgery, with a wider intervertebral space providing

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enhanced anatomical conditions. Despite this strategy's advantages, there is a lack of comparative studies assessing PTED and Endo-LOVE. This study aimed to provide a reference for the clinical application of the two procedures by comparing their clinical efficacy for treating degenerative lumbar spinal stenosis with unilateral radicular pain in the lower extremities.

Materials and Methods

Research Design

The inclusion criteria were as follows: (1) Patients with clinical symptoms including mainly neurogenic intermittent claudication with unilateral radicular pain in the lower limbs without severe low back pain; (2) Central spinal stenosis (central sagittal diameter of the spinal canal <10 mm) or lateral saphenous fossa stenosis (<3 mm in diameter), with or without disc herniation, and with imaging evidence from X-rays, magnetic resonance images (MRIs), and computed tomography (CT) scans; (3) The DLSS is co-diagnosed by at least 3 senior physicians; (4) Conservative treatment for ≥ 3 months with poor symptomatic relief. The exclusion criteria were as follows: (1) Patients with comorbid scoliosis or kyphosis deformity, spinal trauma, tumors, infections, coagulation disorders, or a history of previous lumbar spine surgeries; (2) Power X-rays suggested lumbar spine instability or Meyerding degree $\geq$ Grade I slippage; (3) Those who refused to participate in the study or lost to follow-up.

After being screened by the above criteria, a total of 58 patients with DLSS in combination with unilateral lower extremity radicular pain symptoms, who underwent full endoscopic decompression surgeries from June 2020 to December 2021, were analyzed retrospectively. The PTED procedure was used in 31 cases and the Endo-LOVE procedure in 27 cases. Baseline data were collected, including age, gender, disease duration, and surgical segment (Table 1). Informed patient consent was obtained for this study in accordance with the Declaration of Helsinki, and the study was approved by Yichang Central People's Hospital Ethics Committee (Ethics approval number: 2023-111-01).

Surgical Procedures

PTED Group

Fig. 1A-D showed PTED surgical process: Patients were placed in the prone position. Next, the diseased intervertebral space was marked under fluoroscopy using a guide needle. After disinfecting and spreading the towel, local anesthesia was administered in combination with basic anesthesia. An incision of approximately 7 mm was made in the midline of the diseased intervertebral space at a distance of 9~12 cm. The intervertebral foramen was punctured with a special puncture needle under fluoroscopy at 30° to the body's surface. The position of the puncture needle was confirmed by fluoroscopy to be ventral to the posterior superior margin of the vertebral body through the superior articular process (As shown in Fig. 1A,B). The intervertebral foramen was enlarged, and the nucleus pulposus was removed around the nerve root exit point (As shown in Fig. 1C). The hyperplastic bone continued to be removed, the hypertrophic ligamentum flavum was removed, and the nerve root was loosened. The radiofrequency tip is used to thoroughly clean the loose disc tissue around the nerve roots. The spinal canal was decompressed, and the nerve root was checked to see if the nerve root was well loosened (As shown in Fig. 1D). Next, the lens and the passageway were exited, and the wounds were closed with sterilized dressings.

Endo-LOVE Group

Fig. 1E-H showed Endo-LOVE surgical process: Patients took the prone position. Next, the lesion intervertebral space was located and marked under fluoroscopy using a guide needle. After disinfecting and spreading the towel, local anesthesia was administered in combination with basic anesthesia. An incision of approximately 7 mm was made 1 cm from the midline of the spinous process to establish a working channel. The skin, subcutaneous tissue, and fascia were incised sequentially to insert a dilator and a working trocar, which was confirmed to be located at the medial margin of the articular process under the target vertebral space using fluoroscopy (As shown in Fig. 1E,F). Next, the intervertebral foramenoscopy imaging system was placed and connected to physiological sodium chloride saline for rinsing. The soft tissues outside the vertebral plate were removed with the medullar forceps and radiofrequency cutter head. Part of the vertebral plate was removed using a microscopic coaxial ring saw. Next, part of the vertebral plate was removed, revealing the head and tail side of the ligamentum flavum (As shown in Fig. 1G). The ligamentum flavum was separated from the lateral wall of the spinal canal with a radiofrequency cutter head and basket forceps to explore the lateral nerve. Bone-biting forceps were used to bite off the bone of the lateral saphenous fossa of the lateral spinal canal to enlarge the neural root canal. The next step involved the decompression of the vertebral canal. Subsequently, the passage was rotated to reposition the nerve root and obstruct it from within the dural sac, effectively moving it outside the passage. Following this, radiofrequency ablation was employed to remove the fibrous annulus, thereby exposing the protruding medulla tissues. Finally, the neural root's ventral side and axillary segment were extracted using medullary forceps, thereby successfully eliminating the protruding medulla. The prominent nucleus pulposus tissue in the axillary region was addressed by radiofrequency ablation to alleviate and protrude the nucleus pulposus tissue and the adjacent fibrous ring. Subsequently, a thorough exploration was carried out to loosen the affected nerve root (As shown in Fig. 1H). Once the surgical site achieved complete hemostasis, the instruments were carefully withdrawn from the operative field. The incision was then meticulously sutured, disinfected, and securely bandaged to conclude the procedure. The surgical imaging systems utilized during the procedure consisted exclusively of the Joimax fully visualized intervertebral foraminoscope surgical system (TESSYS® I see, Joimax Inc., Karlsruhe, Germany) (Fig. 1I-L).

Post-Operative Treatment

Post-operative treatments for dehydration, swelling, and pain were administered, as well as nutrition to optimize nerve recovery. Additionally, bed rest for one day after surgery and wearing a lumbar girdle until the second post-operative week for appropriate floor activities were recommended. During the post-operative treatment period, lumbar spine computed tomography (CT) and magnetic resonance images (MRIs) were performed, and the data were carefully reviewed through comparative analysis with the preoperative period to evaluate the decompression of the spinal canal.

Clinical Outcomes Assessment

The operation time, the number of intraoperative fluoroscopies, intraoperative bleeding (intraoperative bleeding = intraoperative negative pressure suction volume – saline flush volume in hanging bag), post-operative hospitalization time, and post-operative complications were recorded in the two groups. Post-operative lumbar spine CT and MRIs data were observed to understand the extent and degree of spinal canal decompression. The Visual Analog Scale (VAS) assessed lower limb pain preoperatively and at post-operative three days, three months, six months, and the final follow-up. The patients' Oswestry Disability Index (ODI) was assessed before and after surgery, and modified MacNab criteria were assessed to determine the extent and degree of the spinal canal decompression at three and six months post-surgery and at the final follow-up. Furthermore, these same measures (ODI and modified MacNab criteria) were used to assess the clinical efficacy at post-surgery three and six months and at the final follow-up.

Radiographic Assessment

All patients were evaluated preoperatively for the degree of stenosis by MRIs, which was graded using the Schizas [7] grading criteria, with grade A defined as no or mild stenosis, grade B as moderate stenosis, grade C as severe stenosis, and grade D as very severe stenosis. Dural sac cross-sectional area (DSCSA) was measured and compared between the two groups of patients based on lumbar spine MRIs at preoperative and final postoperative follow-up using Image J graphic processing software V1.8.0 (National Institutes of Health, Bethesda, MD, USA). We relabeled the scale on the MRI T2WI axial images before each measurement to minimize errors caused by changes in image scaling.2 spine surgeons with more than 10 years of experience jointly measured the minimum values of the DSCSA at the level of two adjacent discs and averaged them.

Statistics Analyses

SPSS version 26.0 was used for statistical analysis (IBM, Armonk, NY, USA). Measurement data were tested for conformity to the normal distribution using the Kolmogorov-Smirnov test and expressed as mean ± standard deviation, the *t*-test was used to compare normal continuous variables, and the Mann-Whitney U-test was used to compare skewed continuous variables; count data were tested using the chi-square test using the number of cases or percentages. ANOVA was used to compare periods within groups, and the two-sided α-value was set at 0.05. A p value < 0.05 was considered statistically significant.

Results

General Information

All the patients completed the 2 procedures and were followed up for over 12 months (31 in the PTED group and 27 in the Endo-LOVE group). The two groups had similar operative times, number of intraoperative fluoroscopies, intraoperative hemorrhages, and length of post-operative hospital stay ($p > 0.05$) (Table 2).

Clinical Efficacy Assessment

Figs. 2,3 show the imaging before and after PTED and Endo-LOVE procedures, respectively, where adequate decompression of the stenosis was obtained. Fig. 4 shows the comparison of leg pain VAS scores at three days, three months, six months, and at the last follow-up, and ODIs at three months, six months, and at the last follow-up compared to preoperative values in the two groups of patients. (A) Post-operative leg pain VAS scores in the PTED group were (2.77 ± 0.62), (1.87 ± 0.62), (1.67 ± 0.59), and (1.29 ± 0.74), respectively, and all of them were significantly lower than the preoperative (6.23 ± 1.26) scores ($p < 0.05$). The post-operative VAS scores in the Endo-LOVE group were (3.01 ± 0.98), (1.93 ± 0.73), (1.70 ± 0.78), and (1.15 ± 0.82), respectively, which were all significantly lower than the preoperative (6.44 ± 1.40) scores ($p < 0.05$). There was no statistically significant difference in VAS scores between the two groups of patients when compared between the groups ($p > 0.05$). (B) The post-operative ODIs in the PTED group were (28.74 ± 9.93)%, (24.97 ± 8.59)%, and (21.84 ± 7.63)%, respectively, all of which were significantly lower ($p < 0.05$) than the preoperative score (54.61 ± 12.54)%. The post-operative ODIs in the Endo-LOVE group were (26.33 ± 7.55)%, (22.81 ± 6.85)%, and (20.30 ± 5.78)%, respectively, all of which were significantly lower ($p < 0.05$) than the preoperative (55.15 ± 13.02)%. There was no statistically significant difference in ODIs between the two patient groups ($p > 0.05$) (Table 3).

Fig. 5 shows the modified MacNab criteria at the last post-operative follow-up of the two groups of patients. The excellent/good rates in the PTED group (n = 31) and the

Table 1. Baseline characteristics for the two groups of patients M (P25, P75).

	PTED (n = 31)	Endo-LOVE (n = 27)	Z/χ^2-value	p-value
Age (yrs)	62 (54, 67)	59 (49, 67)	Z = 0.632	0.527
Gender				
Male	14 (45.2%)	15 (55.6%)	χ^2 = 0.624	0.430
Female	17 (54.8%)	12 (44.4%)		
BMI (kg/m^2)	25.70 (20.80, 27.90)	25.40 (20.80, 28.30)	Z= –0.156	0.876
Duration of disease (months)	11 (6, 15)	9 (6, 14)	Z = –0.500	0.617
Operated segments				
L4/5	22 (71.0%)	16 (59.3%)	χ^2 = 0.876	0.349
L5/S1	9 (29.0%)	11 (40.7%)		
Schizas grade (A/B/C/D)	3/12/15/1	1/9/14/3	χ^2 =2.354	0.308
Follow-up period (months)	16 (14, 17)	16 (15, 17)	Z = –0.442	0.659

Note: A positive Z-value suggests that the median for PTED data is greater than that of Endo-LOVE, and vice versa. BMI, body mass index; PTED, percutaneous transforaminal endoscopic decompression; Endo-LOVE, endoscopic lamina fenestration decompression.

Table 2. Comparison of general surgical conditions between the two groups ($\bar{x} \pm$ s).

	PTED (n = 31)	Endo-LOVE (n = 27)	t-value	p-value
Operating time (min)	47.32 ± 7.67	50.30 ± 6.74	–1.558	0.125
Intraoperative fluoroscopy times	5.26 ± 0.77	4.89 ± 0.96	1.820	0.072
Intraoperative hemorrhage (mL)	48.26 ± 12.24	51.15 ± 15.32	–0.898	0.372
Post-operative hospitalization (days)	3.29 ± 0.82	3.59 ± 1.45	–0.993	0.325

Note: A positive t-value suggests that the mean of the PTED data is greater than that of Endo-LOVE, and vice versa.

Endo-LOVE group (n = 27) were 90.3% (left) and 92.6% (right), respectively, and there was no statistically significant difference in the excellent/good rates between the groups (showed in Table 4) ($p > 0.05$). Table 5 shows that the enlargement of the DSCSA in the Endo-LOVE group was significantly greater than in the PTED group ($p < 0.05$).

Complications

One intraoperative ipsilateral nerve root ependymal injury occurred in the PTED group, resulting in post-operative pins and needles and burning sensations on the lateral side of the calf. The patient was administered methylcobalamin tablets 0.5 mg orally twice daily, and the symptoms disappeared after 12 weeks. Additionally, one case of intraoperative cerebrospinal fluid leakage due to a small tear of the dural sac occurred in the Endo-Love group. The patient was treated by covering the tear with a gelatine sponge and was placed on strict bed rest for seven days. After seven days, this treatment did not affect the patient's ability to get out of bed. Other complications, such as wound infection, important blood vessel injury, and spinal cord hypertension-like syndrome, were not noted.

Discussion

The pathophysiological features of DLSS are lumbar disc herniation, small joint cohesive hyperplasia, hypertrophy of ligamentum flavum, and lumbar spondylolisthesis leading to stenosis of the central spinal canal, lateral saphenous fossa, and neural root canals [8]. As disc hydration diminishes and disc height decreases, the gravitational load is redistributed onto the smaller intervertebral joints and contributes to the proliferation of bone, which can become a cumbersome issue. Hypertrophied and ossified ligaments can compress small arteries, leading to neural ischemia, obstruction of venous blood return, toxic metabolite accumulation, and nerve root damage [9, 10]. These pathophysiological changes often lead to increased pain and numbness in the lower extremities during lumbar extension or walking, reducing the ability of the patient to perform daily activities and decreasing their quality of life. Although spinal stenosis has a wide range of pathological causative factors and variable clinical symptoms, the management of spinal stenosis varies from one procedure to another.

Traditional open surgery requires an incision and extension from the dorsal paravertebral area, as well as peeling off the skin, subcutaneous tissue, and paravertebral muscles layer by layer, resulting in a high incidence of post-operative complications such as medically induced low back pain,

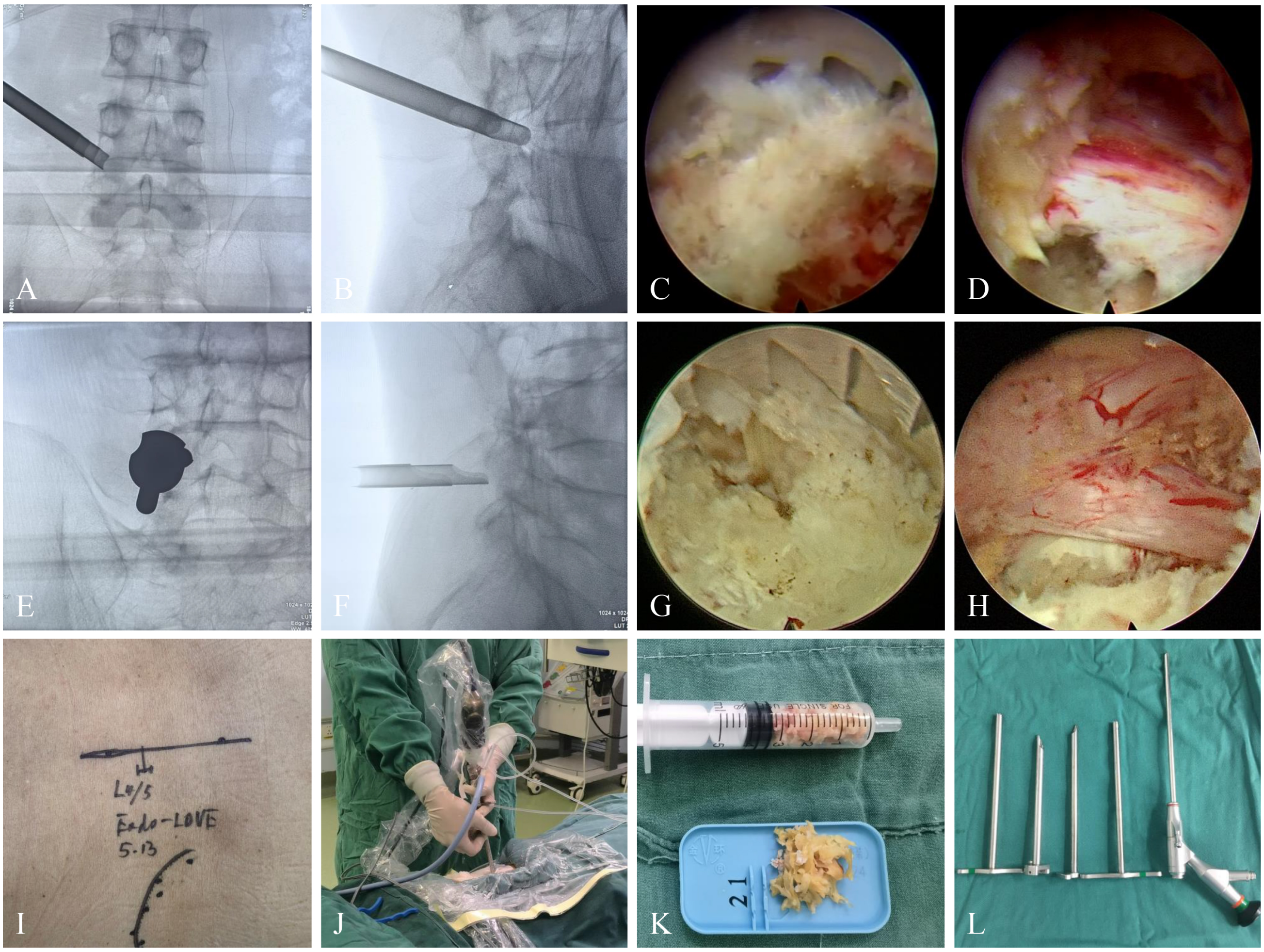

Fig. 1. Intraoperative pictures. (A,B) PTED intraoperatively with working trocar placement under C-arm fluoroscopy. (C,D) Endoscopic resection of the superior articular eminence using a fully visualized circular saw and nerve root decompression after surgery. (E,F) Endo-LOVE intraoperative C-arm fluoroscopy for placement of a working trocar. (G,H) Total endoscopic resection of the lamina and dural sac using a visual ring saw and nerve root decompression after surgery. (I) Endo-LOVE preoperative body surface line drawing for localization. (J) Intraoperative use of total endoscopy by the operator. (K) Intraoperatively removed vertebral plate bone and ligamentum flavum. (L) Surgical instruments, including "U/T" shaped working trocars, fully visualized microscopic circular saws and intervertebral scopes.

incisional infections, secondary segmental instability, and dural tears. Since endoscopic surgery possesses an exponentially enlarged field of view, the nerves, blood vessels, and other structures can be identified, avoiding damage to important structures due to the blind spot and effectively reducing hemorrhage and the aggregation of inflammatory factors [11]. Percutaneous endoscopic lumbar discectomy (PELD) was first introduced by Kambin and Gellman [12] in 1983 and has since been further developed into the Yeung Endoscopic Spine System (YESS) [13] and the Transforaminal Endoscopic Spine System (TESSYS) [14]. In the past, the YESS technique employed the lateral Kambin's triangle to access the intervertebral foramina, facilitating the precise targeting and removal of protruding nucleus pulposus tissue. In contrast, the TESSYS I technique utilizes a visual ring saw to customize the articular eminence as needed, and subsequently eliminates portions of the ligamentum flavum, the protruding nucleus pulposus, and other factors contributing to compression. The TESSYS approach enhances percutaneous transforaminal endoscopic discectomy (PTED) by promoting a safer, more precise, and more efficient bony decompression [15]. This refinement in technique allows for the comprehensive endoscopic treatment of various forms of spinal stenosis. The classic posterior lumbar laminectomy with open window decompression (LOVE) has been used for nearly one hundred years [16], and after continuous improvement of the technique, Jiang *et al*. [6] proposed the all-endoscopic interlaminectomy with open window decompression (Endo-LOVE), which can sufficiently decompress the dural sac and dorsal side of the nerve root and provide 360° release of the S1 nerve root, achieving multiplanar and three-dimensional decompression of the spinal canal. The resection range of this modified technique is precise and control-

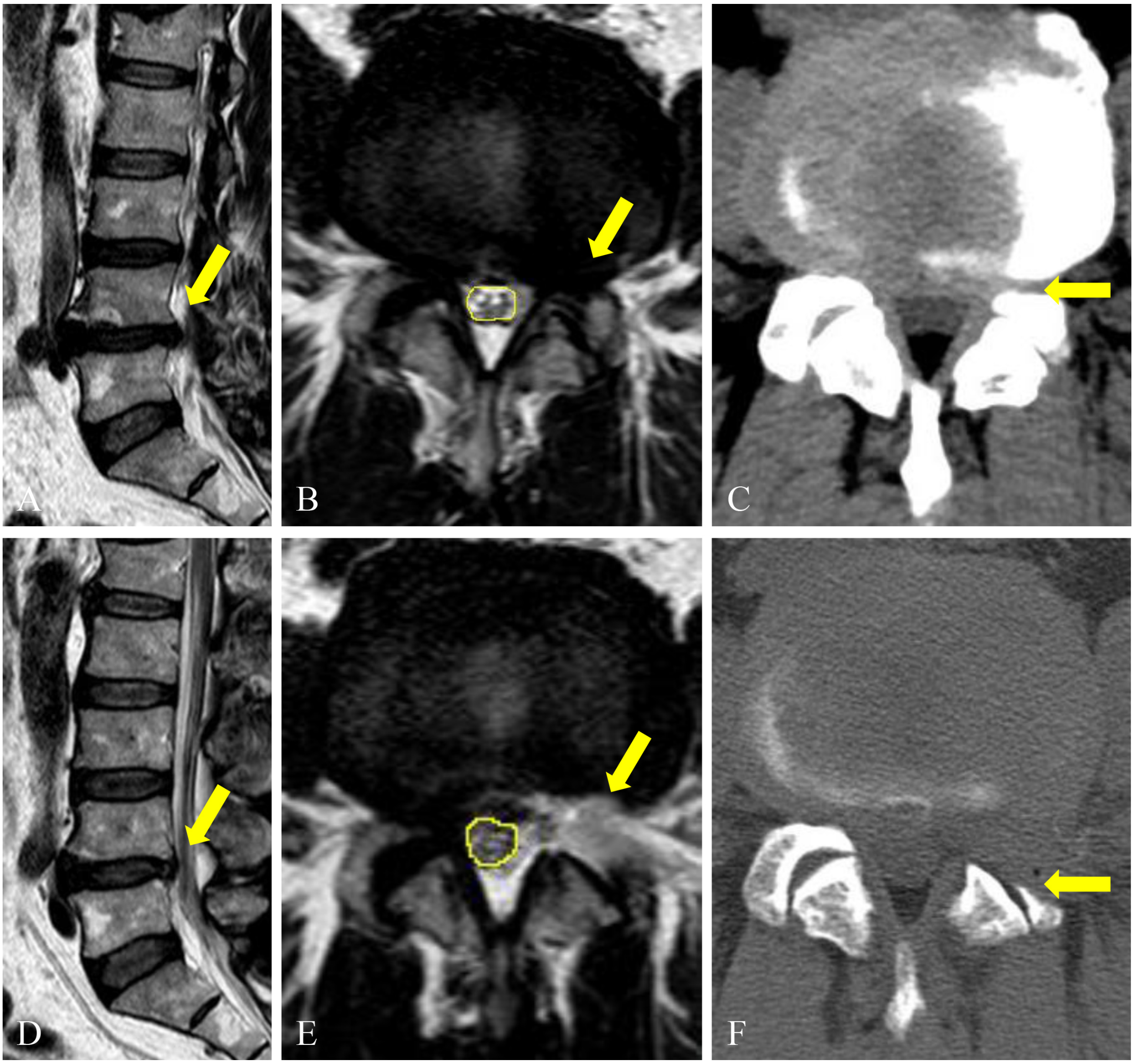

Fig. 2. Pre and post-operative imaging of PTED. (A–C) Preoperative magnetic resonance image (MRI) and computed tomography (CT) suggested left lateral recess stenosis and L5 nerve root compression (yellow arrows). Pre-operative measurement of dural sac cross-sectional area (DSCSA) was 76.14 mm^2 (the yellow boxed area). (D–F) Post-operative MRI and CT suggested adequate decompression of the left nerve root canal (yellow arrows). Post-operative measurement of DSCSA was 101.02 mm^2 (the yellow boxed area).

lable, and it is now possible to complete Endo-LOVE by small-channel endoscopic posterior approach under basic anesthesia, which is conducive to the patients' early post-operative mobilization.

In this study, there was no significant difference in operating time, intraoperative fluoroscopy times, intraoperative hemorrhage, or post-operative hospitalization between the PTED and Endo-LOVE groups, and there was no statistically significant difference in the reduction of leg pain VAS scores or ODIs. The excellent rates in the modified MacNab criteria at the final postoperative follow-up were 90.3% and 92.6% in both groups, and both procedures were effective in expanding the DSCSA and relieving nerve compression symptoms. Ogura *et al*. [17] suggested that the inclusion of T1-weighted in the measurement process could reduce the measurement error; in addition, it has been suggested that a DSCSA of less than 70 mm^2 is defined as severe spinal stenosis [18]; however, there is no conclusive evidence of a significant association between the DSCSA and clinical symptoms [19]. In this study, the enlargement of DSCSA in the Endo-LOVE group was better than that in the PTED group at the final follow-up, but there was no significant difference in the reduction of VAS and ODI between the two groups. These data indicate that the two surgical pro-

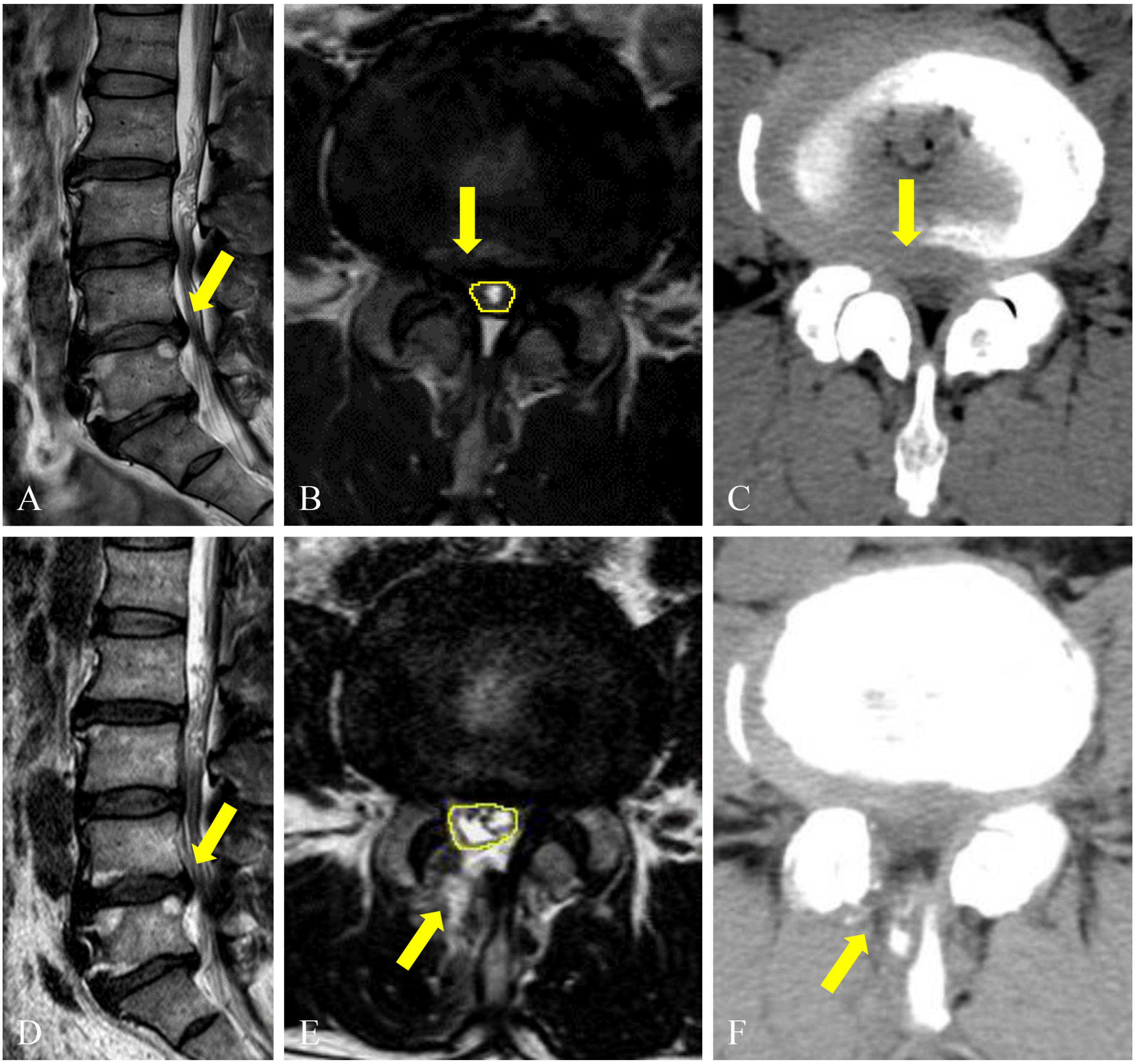

Fig. 3. Endo-LOVE pre- and post-operative imaging. (A–C) Preoperative MRI and CT suggested central spinal stenosis with hypertrophy of the ligamentum flavum and dural sac compression (yellow arrows). Pre-operative measurement of DSCSA was 41.69 mm^2 (the yellow boxed area). (D–F) Post-operative MRI and CT suggested adequate decompression of the left lateral saphenous fossa (yellow arrows). Post-operative measurement of DSCSA was 122.83 mm^2 (the yellow boxed area).

cedures were minimally invasive, had quick recovery, and had satisfactory post-operative outcomes. Both procedures were done under local or basic anesthesia, with a low rate of anesthesia-related complications [10], avoiding the risks associated with general anesthesia endotracheal intubation and anesthesia resuscitation in elderly patients with complex underlying diseases. Additionally, clinicians could receive immediate pain feedback from the patient in case of minor intraoperative stimulation, reminding the surgeon to avoid damaging the nerves. Both procedures require no repeated fluoroscopy to locate the puncture target precisely, and both are performed with less fluoroscopy.

The key to PTED is understanding the relationship between the responsible segment and the highest level of the iliac crest in detail before surgery. We recommend that a clinician press the spinous processes by hand to determine the location of the responsible segment, i.e., the puncture point, disinfect and spread the towel, and administer local anesthesia. The clinician should then directly insert the needle roughly to the intervertebral foramen of the responsible intervertebral space, which can be adjusted at the appropriate time to adjust the position of the puncture needle and place the channel. After placing the channel, the method allows for the flexible adjustment of the channel's position

Table 3. VAS and ODI scores before and after surgery in the 2 groups ($\bar{x} \pm$ s).

	Times	PTED (n = 31)	Endo-LOVE (n = 27)	*t*-value	*p*-value
VAS scores	Pre-Op	6.23 ± 1.26	6.44 ± 1.40	–0.628	0.533
	3-Days	2.77 ± 0.62*	3.01 ± 0.98*	–1.239	0.221
	3-Mons	1.87 ± 0.62*	1.93 ± 0.73*	–0.310	0.757
	6-Mons	1.67 ± 0.59*	1.70 ± 0.78*	–0.145	0.885
	Final follow-up	1.29 ± 0.74*	1.15 ± 0.82*	0.695	0.490
ODI (%)	Pre-Op	54.61 ± 12.54	55.15 ± 13.02	–0.159	0.874
	3-Mons	28.74 ± 9.93*	26.33 ± 7.55*	1.027	0.309
	6-Mons	24.97 ± 8.59*	22.81 ± 6.85*	1.044	0.301
	Final follow-up	21.84 ± 7.63*	20.30 ± 5.78*	0.857	0.395

*, $p < 0.05$. VAS, Visual Analogue Score; ODI, Oswestry Disability Index.

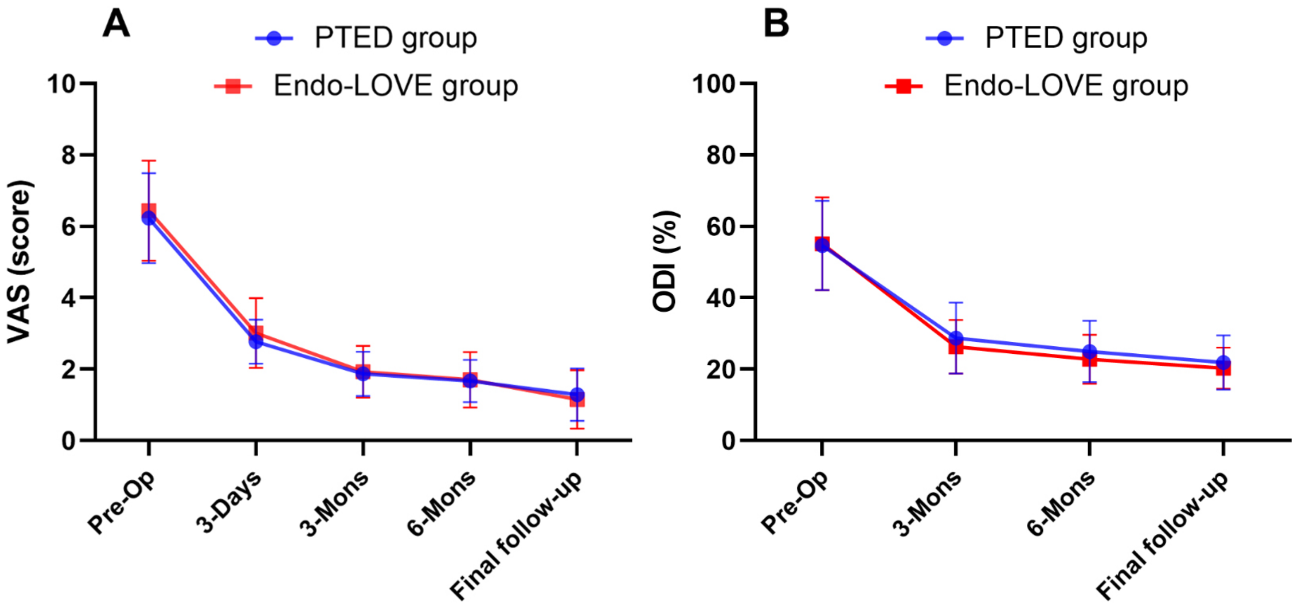

Fig. 4. Clinical outcomes before and after the surgery at different follow-up time points between the two groups. (A) VAS scores for leg pain. (B) ODI before and after PTED and Endo-LOVE surgery.

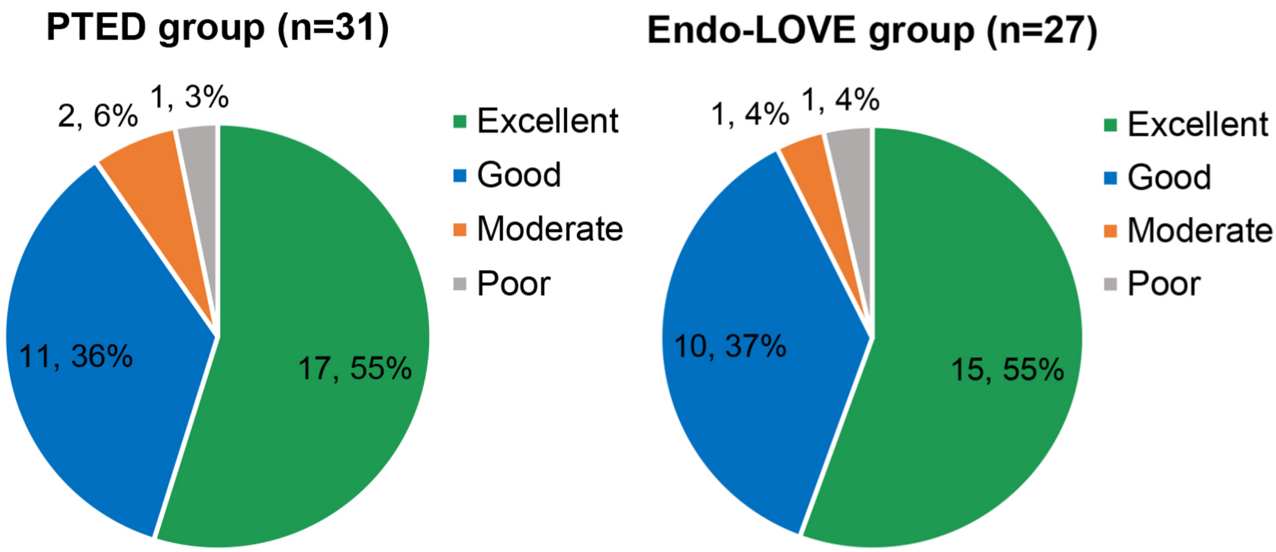

Fig. 5. Outcome of the modified MacNab criteria.

Table 4. Outcome of the modified MacNab criteria between the two groups.

	PTED	Endo-LOVE
Excellent (n, %)	17 (55%)	15 (55%)
Good (n, %)	11 (36%)	10 (37%)
Moderate (n, %)	2 (6%)	1 (4%)
Poor (n, %)	1 (3%)	1 (4%)
χ^2-value	0.231	
p-value	0.972	

Table 5. Change in DSCSA at pre-operative and last post-operative follow-up ($\bar{x} \pm$ s).

	PTED	Endo-LOVE	t-value	p-value
Pre-operative DSCSA (mm^2)	63.58 $\pm$ 15.63	58.89 $\pm$ 19.25	1.024	0.310
Post-operative DSCSA (mm^2)	116.53 $\pm$ 14.96	122.18 $\pm$ 22.27	–1.149	0.256
D-value of DSCSA (mm^2)	52.95 $\pm$ 17.62	63.29 $\pm$ 17.74	–2.224	$<$0.05

Note: A positive t-value suggests that the mean of the PTED of data is greater than that of Endo-LOVE, and vice versa.

based on the anatomical position of the scope to reduce the number of fluoroscopies. In the context of Endo-LOVE, precise positioning within the target intervertebral space is all that is required. The intervertebral foramina are meticulously exposed stepwise and directly visualized to confirm their alignment. This confirmation typically occurs approximately four times during the preoperative positioning adjustments and channel placement, substantially reducing the number of fluoroscopies required.

We believe that PTED is more suitable for DLSS patients with lumbar disc herniation with lateral recess stenosis. Specifically, PTED is particularly effective for managing the paracentral lateral type of spinal stenosis characterized by predominantly ventral nerve root compression. The operator must first microscopically locate the superior articular process to treat patients with this disease presentation. For the stenosis of different responsible sites, the visual ring saw can select the apical, ventral, basal, or superior articular process combined with inferior articular process molding for the superior articular process [20–23]. Next, the surgeon will remove the protruding nucleus pulposus tissues and decompress the lateral saphenous fossa, which reduces the nuisance to the dural sac and, in some cases, enables a comprehensive 270° decompression of the nerve root. This strategy can make it more convenient to excise the hyperplastic ossification of the posterior margins of the vertebral body, reducing the pull and push on the nerve root of the posterior pathway. When dealing with stenosis caused by hypertrophy of the ligamentum flavum, adequate ventral decompression should be performed first to allow the nerve root to "fall back" in order to increase the operating space between the dorsal side of the nerve root and the ligamentum flavum, and then the central canal can be enlarged dorsally according to the pathologic factors of compression, which can better enhance the safety of dorsal decompression [24]. Ventral decompression also avoids excessive resection of the dorsal aspect of the lesser articular eminence and reduces the incidence of medically induced instability due to the destruction of posterior structures [25, 26]. Cheng *et al.* [26] used PTED under local anesthesia to treat patients with DLSS with lumbar Grade I slippage by releasing the ipsilateral hypertrophied ligamentum flavum and posterior longitudinal ligament. Those authors also performed contralateral central spinal canal decompression, with satisfactory clinical results in the early post-operative period. It should be noted that the higher the surgical segment, the closer the dorsal root ganglion is to the medial edge of the pedicle, so repeated puncture via the intervertebral foramen and paracentesis, which may cause an abnormal or aggravated sensation in the lower limbs after surgery, should be avoided. Wang *et al.* [27] concluded that inadequate PTED foraminoplasty and compression by residual bony residue were the causes of post-operative radicular symptoms. In the present study, the operator molded the articular eminence under direct vision, effectively avoiding a series of problems caused by inadequate or excessive decompression of the intervertebral foraminal region.

Endo-LOVE decompresses the bone, ligamentum flavum, and part of the intervertebral disc dorsally and can also enter the contralateral spinal canal to perform contralateral submerged decompression by adjusting the working channel, providing a more extensive range of decompression, and is effective in dealing with bilateral DLSS. This strategy is known as the "over-the-top" technique [28, 29], which has certain advantages in facing some cases of high iliac crests. According to Jiang *et al.* [6], the puncture path of Endo-LOVE should be located at the upper edge of the intervertebral plate space, perpendicular to the inferior articular process and pointing to the plane of the intervertebral space because the inferior articular process is closer to the central spinal canal. Its hyperplasia and cohesion are more prone to cause spinal stenosis, so decompression of the disc planes and shaping of the inferior articular process are crucial. Their study's results confirmed that Endo-LOVE was also effective in the lateral saphenous fossa and the neurapraxic canal stenosis. Endo-LOVE uses fully visualized annular saws to enlarge the intervertebral plate space to treat the hypertrophied ligamentum flavum, the small articular eminence cohesive osteophyte, and the central herniated intervertebral discs. This intervention effectively enlarges the intravertebral canal volume, thus reducing the direct compression of the nerves and improving the venous return of the blood in the spinal canal. Our data indicate that Endo-LOVE is more suitable for DLSS patients with intermittent claudication as the main symptom of radicular pain in the lower limbs and dorsal compression as the causative factor. However, the surgical instruments of the posterior approach inevitably cause different degrees of harassment of the dural sac and traversing nerve roots. Post-operative sensory numbness or even weakness can occur, and using the pressure and mobility of the water medium to separate the dural sac and the nerve roots can be advantageous to improving surgical outcomes.

The treatment of highly free medullary nuclei and lateral socket stenosis is a challenging procedure. Although PTED can decompress and deal with free nucleus pulposus tissue to the distal region and even complete lateral saphenous fossa decompression via the superior pedicle margin approach, more bone at the base of the superior articular eminence needs to be shaped, and its medical stability and bleeding from the bone trauma should not be ignored. The endoscopic decompression through bilateral transforaminal approach proposed by Zhang *et al.* [30] for the treatment of severe central spinal stenosis due to lateral saphenous fossa stenosis has satisfactory efficacy, but it is easier to injure the cauda equina in patients with severe bony stenosis of the central spinal canal, and it is more demanding for beginners. Endo-LOVE can achieve the same result by tilting the channel laterally and enlarging the resection of a portion of the inferior articular eminence of the superior vertebral body. However, the stability of the articular eminence and nerve root intrusion are also of concern. An *et al.* [31] studied paraspinal muscle MRIs of 159 patients who underwent Endo-ULBD surgery and concluded that decompression was sufficient while still adequately preserving segmental stability and mobility. The most significant advantage of PTED in this study is that it is more direct in releasing the nerve root's ventral compression, especially in treating unilateral lateral saphenous fossa and stenosis of the nerve root canal. While dorsal decompression is theoretically possible, it necessitates the resection of additional articular eminences. However, this poses challenges in maintaining the stability of the small joints due to the excessive bone destruction involved. Therefore, the posterior Endo-LOVE is safer more direct when faced with dorsal ligamentum flavum hypertrophy and intra-articular synostosis with central/paracentral stenosis, axillary nucleus pulposus compression, and highly free nucleus pulposus protrusion with calcification.

Although endoscopic simple decompression surgery has been of increasing interest and benefit to patients and practitioners, it is associated with a small range of visual fields and a relatively homogenous range of surgical instruments. Poor patient tolerance, inaccurate preoperative fluoroscopic positioning, inappropriate placement of the working trocar, high water pressure in the total endoscopic flush, and unskilled handling make the procedure challenging. Patients with combined multisegmental degeneration often experience increased stress at the lesion location, long disease duration, and severe segmental deformation, facing greater surgical difficulty and risk [32]. Additionally, the learning curve in the preoperative period, good puncture technique, and proficiency in microscopic manipulation are the keys to completing the surgery.

The present study is a single-center retrospective study with a small sample size, a short follow-up period, and narrower indications for inclusion. In the future, as we continue to gain proficiency, experience with the procedure and optimize the equipment, we will conduct multicentre studies with long-term follow-up, broader indications, and larger sample sizes.

Conclusions

In summary, both procedures are safe and effective in the treatment of DLSS with unilateral lower extremity radicular pain. PTED is suitable for DLSS with unilateral lower extremity radicular pain in the case of ventral lumbar disc herniation with lateral recess stenosis, which is a paracentral stenosis with ventral compression of the nerve root; whereas Endo-LOVE is more suitable for DLSS of unilateral lower extremity radicular pain with dorsal compression as the main pathogenetic factor. We should be specific about the choice of spinal stenosis treatment.

Availability of Data and Materials

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Author Contributions

FL and HZ designed the research study. LX and ZZ performed the research. ML, YD and BL provided help and advice on surgical details. LX analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Informed patient consent was obtained for this study in accordance with the Declaration of Helsinki, and the study was approved by Yichang Central People's Hospital Ethics Committee (Ethics approval number: 2023-111-01).

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Xie P, Feng F, Chen Z, He L, Yang B, Chen R, *et al*. Percutaneous transforaminal full endoscopic decompression for the treatment of lumbar spinal stenosis. BMC Musculoskeletal Disorders. 2020; 21: 546.

[2] Rudnicka E, Napierała P, Podfigurna A, Męczekalski B, Smolarczyk R, Grymowicz M. The World Health Organization (WHO) approach to healthy ageing. Maturitas. 2020; 139: 6–11.

[3] Zhou C, Zhang G, Panchal RR, Ren X, Xiang H, Xuexiao M, *et al*. Unique Complications of Percutaneous Endoscopic Lumbar Discectomy and Percutaneous Endoscopic Interlaminar Discectomy. Pain Physician. 2018; 21: E105–E112.

[4] Tarawneh OH, Garay-Morales S, Liu IZ, Pakhchanian H, Kazim SF, Roster K, *et al*. Impact of COVID-19 on Spinal Diagnosis and Procedural Volume in the United States. Global Spine Journal. 2023; 21925682231153083.

[5] Chen Z, Zhang L, Dong J, Xie P, Liu B, Chen R, *et al*. Percutaneous Transforaminal Endoscopic Discectomy Versus Microendoscopic Discectomy for Lumbar Disk Herniation: Five-year Results of a Randomized Controlled Trial. Spine. 2023; 48: 79–88.

[6] Jiang Q, Ding Y, Lu Z, Cui H, Zhang J, Fu B, *et al*. Comparative Analysis of Non-Full and Full Endoscopic Spine Technique via Interlaminar Approach for the Treatment of Degenerative Lumbar Spinal Stenosis: A Retrospective, Single Institute, Propensity Score-Matched Study. Global Spine Journal. 2023; 13: 1509–1521.

[7] Schizas C, Theumann N, Burn A, Tansey R, Wardlaw D, Smith FW, *et al*. Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images. Spine. 2010; 35: 1919–1924.

[8] Katz JN, Zimmerman ZE, Mass H, Makhni MC. Diagnosis and Management of Lumbar Spinal Stenosis: A Review. JAMA. 2022; 327: 1688–1699.

[9] Deer TR, Grider JS, Pope JE, Falowski S, Lamer TJ, Calodney A, *et al*. The MIST Guidelines: The Lumbar Spinal Stenosis Consensus Group Guidelines for Minimally Invasive Spine Treatment. Pain Practice: the Official Journal of World Institute of Pain. 2019; 19: 250–274.

[10] Lv Z, Jin L, Wang K, Chen Z, Li F, Zhang Y, *et al*. Comparison of Effects of PELD and Fenestration in the Treatment of Geriatric Lumbar Lateral Recess Stenosis. Clinical Interventions in Aging. 2019; 14: 2187–2194.

[11] Cao S, Cui H, Lu Z, Zhu K, Fu B, Li W, *et al*. "Tube in tube" interlaminar endoscopic decompression for the treatment of lumbar spinal stenosis: Technique notes and preliminary clinical outcomes of case series. Medicine. 2019; 98: e17021.

[12] Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine: A preliminary report. Clinical Orthopaedics and Related Research (1976-2007). 1983; 174: 127–132.

[13] Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: Surgical technique, outcome, and complications in 307 consecutive cases. Spine. 2002; 27: 722–731.

[14] Hoogland T, Schubert M, Miklitz B, Ramirez A. Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases. Spine. 2006; 31: E890–E897.

[15] Pan M, Li Q, Li S, Mao H, Meng B, Zhou F, *et al*. Percutaneous Endoscopic Lumbar Discectomy: Indications and Complications. Pain Physician. 2020; 23: 49–56.

[16] Truumees E. A history of lumbar disc herniation from Hippocrates to the 1990s. Clinical Orthopaedics and Related Research. 2015; 473: 1885–1895.

[17] Ogura H, Miyamoto K, Fukuta S, Naganawa T, Shimizu K. Comparison of magnetic resonance imaging and computed tomography-myelography for quantitative evaluation of lumbar intracanalar cross-section. Yonsei Medical Journal. 2011; 52: 137–144.

[18] Marawar SV, Ordway NR, Madom IA, Tallarico RA, Palumbo M, Metkar U, *et al*. Comparison of Surgeon Rating of Severity of Stenosis Using Magnetic Resonance Imaging, Dural Cross-Sectional Area, and Functional Outcome Scores. World Neurosurgery. 2016; 96: 165–170.

[19] Chung SW, Kang MS, Shin YH, Baek OK, Lee SH. Postoperative expansion of dural sac cross-sectional area after unilateral laminotomy for bilateral decompression: correlation with clinical symptoms. Korean Journal of Spine. 2014; 11: 227–231.

[20] Qiao P, Xu T, Zhang W, Fang Z, Ding W, Tian R. Foraminoplasty affects the clinical outcomes of discectomy during percutaneous transforaminal endoscopy: a two-year follow-up retrospective study on 64 patients. The International Journal of Neuroscience. 2021; 131: 1–6.

[21] Ouyang ZH, Tang M, Li HW, Zou MX, Li XL, Wang WJ, *et al*. Full-Endoscopic Foraminoplasty Using a Visualized Bone Reamer in the Treatment of Lumbar Disc Herniation: A Retrospective Study of 80 Cases. World Neurosurgery. 2021; 149: e292–e297.

[22] Yang F, Li P, Zhao L, Chang C, Chen B. Foraminoplasty at the Base of the Superior Articular Process with Bone Drilling for Far-Downward Discs in Percutaneous Endoscopic Lumbar Discectomy: A Retrospective Study. Journal of Pain Research. 2021; 14: 3919–3925.

[23] Bao BX, Zhou JW, Yu PF, Chi C, Qiang H, Yan

H. Transforaminal Endoscopic Discectomy and Foraminoplasty for Treating Central Lumbar Stenosis. Orthopaedic Surgery. 2019; 11: 1093–1100.

[24] Cheng XK, Chen B. Percutaneous Transforaminal Endoscopic Decompression for Geriatric Patients with Central Spinal Stenosis and Degenerative Lumbar Spondylolisthesis: A Novel Surgical Technique and Clinical Outcomes. Clinical Interventions in Aging. 2020; 15: 1213–1219.

[25] Shin SH, Bae JS, Lee SH, Keum HJ, Kim HJ, Jang WS. Transforaminal Endoscopic Decompression for Lumbar Spinal Stenosis: A Novel Surgical Technique and Clinical Outcomes. World Neurosurgery. 2018; 114: e873–e882.

[26] Cheng XK, Cheng YP, Liu ZY, Bian FC, Yang FK, Yang N, *et al*. Percutaneous transforaminal endoscopic decompression for lumbar spinal stenosis with degenerative spondylolisthesis in the elderly. Clinical Neurology and Neurosurgery. 2020; 194: 105918.

[27] Wang A, Si F, Wang T, Yuan S, Fan N, Du P, *et al*. Early Readmission and Reoperation After Percutaneous Transforaminal Endoscopic Decompression for Degenerative Lumbar Spinal Stenosis: Incidence and Risk Factors. Risk Management and Healthcare Policy. 2022; 15: 2233–2242.

[28] Siepe CJ, Sauer D, Michael Mayer H. Full endoscopic, bilateral over-the-top decompression for lumbar spinal stenosis. 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. 2018; 27: 563–565.

[29] Komp M, Hahn P, Oezdemir S, Giannakopoulos A, Heikenfeld R, Kasch R, *et al*. Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar versus microsurgical laminotomy technique: a prospective, randomized, controlled study. Pain Physician. 2015; 18: 61–70.

[30] Zhang B, Kong Q, Yan Y, Feng P. Degenerative central lumbar spinal stenosis: is endoscopic decompression through bilateral transforaminal approach sufficient? BMC Musculoskeletal Disorders. 2020; 21: 714.

[31] An JW, Kim HS, Raorane HD, Hung WP, Jang IT. Postoperative Paraspinal Muscles Assessment After Endoscopic Stenosis Lumbar Decompression: Magnetic Resonance Imaging Study. International Journal of Spine Surgery. 2022; 16: 353–360.

[32] Cai XY, Sun MS, Huang YP, Liu ZX, Liu CJ, Du CF, *et al*. Biomechanical Effect of L_4 -L_5 Intervertebral Disc Degeneration on the Lower Lumbar Spine: A Finite Element Study. Orthopaedic Surgery. 2020; 12: 917–930.