Trephine-based foraminoplasty in PTED treatment of lumbar lateral recess stenosis

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Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online) *Adv Clin Exp Med*. 2022;31(4):359–367

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Funding sources
None declared

Conflict of interest
None declared

Received on July 7, 2021
Reviewed on October 5, 2021
Accepted on December 7, 2021

Published online on January 24, 2022

Abstract

Background. During minimally invasive spine surgery, nerve root decompression is challenging due to the anatomical division and uncertainty in lumbar lateral recess (LLR).

Objectives. To evaluate the outcome and safety of foraminoplasty using percutaneous transforaminal endoscopic decompression (PTED) (performed with an aid of a trephine) in the treatment of lumbar lateral recess stenosis (LLRS).

Materials and methods. All operations were performed under local anesthesia and in prone position. The puncture point was 10–14 cm away from the midline of the spinous process. One hundred eight individuals with LLRS who underwent PTED from September 2016 to December 2020 in our hospital were enrolled in the study. Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores were collected preoperatively after 1 day, 7 days, 1 month and at the final follow-up (June 2021). Low back pain and leg pain were measured using VAS score. Functional outcomes were assessed with ODI and modified Macnab criteria.

Results. After the surgery, the VAS score and ODI were statistically significant at all follow-up points compared with the pre-surgery (both $p < 0.05$). Based on the modified Macnab scores at the final follow-up, the satisfaction rate at postoperative 1 month was 96.3% and the satisfaction rate at postoperative 7 days was 70.38%. A significant difference was observed between the 2 groups ($p < 0.05$).

Conclusions. Foraminoplasty using PTED performed with a trephine is one of the safe and effective, minimally invasive methods to treat LLRS.

Key words: trephine, percutaneous transforaminal endoscopic decompression, lumbar lateral recess stenosis, foraminoplasty

Cite as
Wang X, Wu L, Zhao K, et al. Trephine-based foraminoplasty in PTED treatment of lumbar lateral recess stenosis. *Adv Clin Exp Med*. 2022;31(4):359–367. doi:10.17219/acem/144638

DOI
10.17219/acem/144638

Background

In 1954, Dutch neurosurgeon Henk Verbiest first defined lumbar spinal stenosis (LSS), bony canal stenosis and neurogenic claudication.[1] Lumbar lateral recess stenosis (LLRS) is a type of LSS. Based on the anatomical types, LLRS can occur in the retrodiscal space, upper part of bony lateral recess and lower part of bony lateral recess (Fig. 1).[2,3] Lumbar lateral recess stenosis indicates that the sagittal diameter of the bone canal is less than 3.0 mm and the diameter of the soft tissue tube is less than 1.0 mm, with varying degrees of lower limb pain, numbness and intermittent claudication.[4]

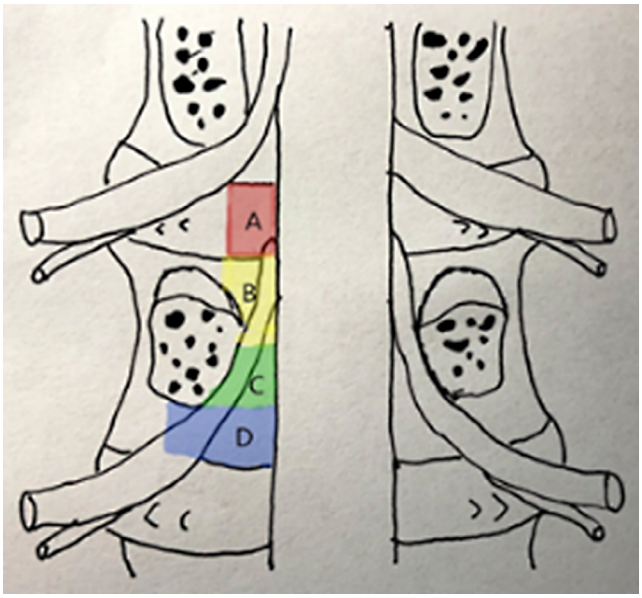

Fig. 1. Schematic diagram of A. retrodiscal space; B. upper part of bony lateral recess; C. lower part of bony lateral recess; D. intervertebral foramen

Several surgical options exist for the treatment of LLRS – foraminotomy, partial facetectomy, total laminectomy, posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF).[5] However, these surgical approaches cause several complications such as muscle trauma, severe bleeding, high hospitalization costs, and fracture of internal fixator, which influence the stability of the spine.[6–9]

Schreiber et al. first applied endoscopic technology for percutaneous nucleus pulposus removal in 1989.[10] With the development of endoscopic theory and equipment, Hoogland designed Transforaminal Endoscopic Spine System (TESSYS), which positions the tip of the superior articular process (SAP) using multistage trephine to grind the tip of SAP (Fig. 2).[11] Yuan et al.[12] applied this technique to treat 48 cases of lumbar disc herniation (LDH) and obtained good results. However, for LLRS, the base of SAP blocked the working channel; LLR decompression was not complete. Therefore, the operation of foraminoplasty under the working channel is limited and the decompression takes

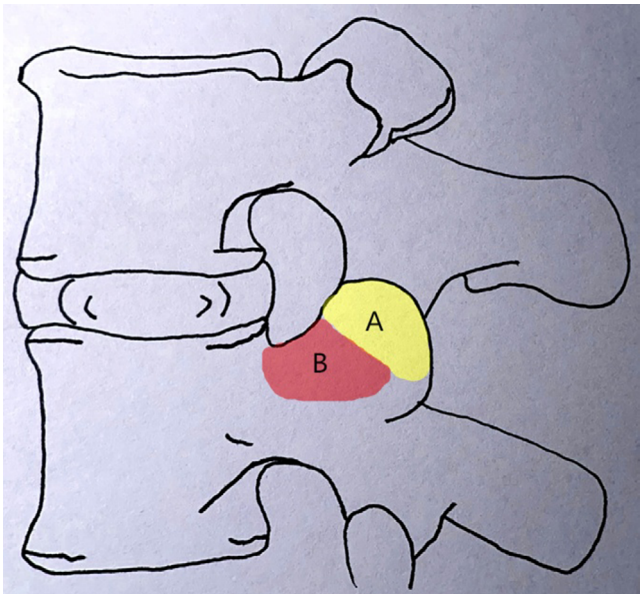

Fig. 2. Schematic diagram of A. the tip of the superior articular process (SAP); B. the bottom of the SAP

longer. The exiting root is easily injured by compression of working tube. The base of SAP is far away from exiting root, which is closer to the bony part of LLR. The 7.6 mm-diameter trephine rather than multistage trephine is easier to remove the base of SAP for foraminoplasty. This method is economical and effective, as well as it reduces the number of radiation leakage. In this study, percutaneous transforaminal endoscopic decompression (PTED) was applied with an aid of trephine to treat patients with LLRS, and the clinical outcomes were analyzed.

Objectives

The aim of this study was to evaluate the outcome and safety of foraminoplasty using percutaneous transforaminal endoscopic decompression (PTED) (performed with an aid of a trephine) to treat lumbar lateral recess stenosis.

Materials and methods

General information

This is a retrospective study. A total of 108 individuals with LLRS were assessed by 2 spine surgeons between September 2016 and December 2020. Those who were selected to undergo PTED with an aid of trephine for LLRS were invited to participate in the study. The inclusion criteria were as follows: (1) the imaging data were complete, consistent with clinical symptoms and signs, and the diagnosis of single-segment LLRS was clear; (2) some patients present with worse symptoms after receiving conservative treatment, which severely affects the quality of life; (3) patients

with coronary artery insufficiency, heart failure, diabetes, respiratory failure, etc. Exclusion criteria were as follows: (1) preoperative imaging data showed spinal instability such as spondylolisthesis and spondylolysis; (2) neurogenic diseases, such as cauda equina syndrome; (3) spinal deformity, spinal tumor or other diseases; (4) the iliac crest for L5-S1 segment was too high (the X-ray suggested that the theoretical puncture passage was blocked by ilium); (5) surgical contraindications (such as important organ dysfunction and bleeding tendency).

The present study followed the principles outlined in the Declaration of Helsinki, received an approval (No. KY2021-260) from our local hospital ethics committee (the Second Affliated Hospital of Harbin Medical University, China) and patients provided informed consent regarding the publication of their data.

Surgical technique

All operations were performed under local anesthesia and in prone position. Puncture point was 10–14 cm away from the midline of the spinous process. The vertical distance of the head side was 2–5 cm, and the puncture needle was inclined at approx. 25° to the horizontal. The average abduction angle of the puncture needle was 30–50°. Under anteroposterior and lateral fluoroscopy, the puncture needle reaches the base of SAP of the inferior vertebral body of the target intervertebral space.

Besides, the procedure was performed under local infiltration anesthesia induced with 0.7% lidocaine. The puncture needle was inserted and located at the bottom of SAP of the diseased segment, and the facet joint was anesthetized on the surface. Next, we removed the needle core, inserted the guidewire, made an 8.0 mm skin incision along with the needle entry point, and placed a four-stage dilatation catheter (Spinendos, Munich, Germany) step by step along the guidewire. These devices were placed at the inner edge of the pedicle under the anteroposteric X-ray, and at the anterior and lower edge of the superior articular process under the lateral X-ray. A 7.6 mm-diameter trephine (Spinendos) was introduced at the base of the SAP, so as to form the SAP.

The trephine was used to remove the partial base of SAP under fluoroscopic guidance. The space formed in this way can be more conducive for the subsequent work tube to access LLR. The procedure is performed in the working tube through the deformed SAP, and targeted decompression is conducted according to the LLRS type, including soft tissue and bony compression. If LLRS is biased to intervertebral foramen and retrodiscal space, the medial and ventral SAP are mainly removed; if the stenosis is partial to bony stenosis, the partial bottom of the SAP is largely removed. Therefore, the plastic scheme is in most cases designed in advance based on the preoperative magnetic resonance imaging (MRI) and computed tomography (CT) image data. Then, it is adjusted according to the specific conditions during the operation. A representative case treated with trephine foraminoplasty is illustrated in Fig. 3,4.

Evaluation of the curative effect

All patients were followed up (including outpatient and telephone follow-up), and the relevant indexes were recorded preoperatively, 1 day, 7 days, 1 month after the operation, and at the final follow-up. In this process, Visual Analogue Scale (VAS) was used to evaluate low back pain before and after the operation; Oswestry Disablity Index (ODI) was applied to evaluate the functional recovery of lumbar vertebrae before and after the operation; the modified Macnab standard was employed to evaluate the curative effect of the operation.

Statistical analyses

The data were processed using IMB SPSS v. 23.0 statistical software (IBM Corp., Armonk, USA), in which the measurement data such as VAS and ODI were presented with median (M), lower quartile (Q_L) and upper quartile (Q_U). All the data were analyzed with Shapiro–Wilk normality test and homogeneity of variance test. Comparisons of the continuous parameters were performed using the repeated measures analysis of variance (ANOVA) test when a normal distribution was present, and using the Kruskal–Wallis test when a normal distribution was absent. The numerical data were compared with the χ^2 test. The value of $p < 0.05$ reflects statistical significance. In this study, operation time, intraoperative bleeding volume, ODI, and VAS did not meet normal distribution.

Results

All operations were successfully completed and were followed up postoperatively after 1 day, 7 days, 1 month, and at the final follow-up 1 year after the operation, in June 2021. The operation time ranged from 60 min to 125 min, with an average of 88.74 min. The intraoperative bleeding volume ranged from 5 mL to 18 mL, with an average of 9.49 mL (Table 1). There were no related complications such as spinal instability, dural leakage or vascular or nerve injury. The VAS score and ODI of low back pain before the operation, on day 1, day 7, after 1 month, and at the final postoperative follow-up were compared. The postoperative scores were higher than those at the preoperative stage (Table 2, Fig. 5–7).

All the indexes improved, and the difference was statistically significant ($p < 0.05$). The symptom efficacy of the patients was evaluated with modified Macnab standard. Particularly, according to the Macnab standard, 1 month after the operation, 88 cases were excellent, 16 cases were good, and 4 cases were fair; the excellent and good rates

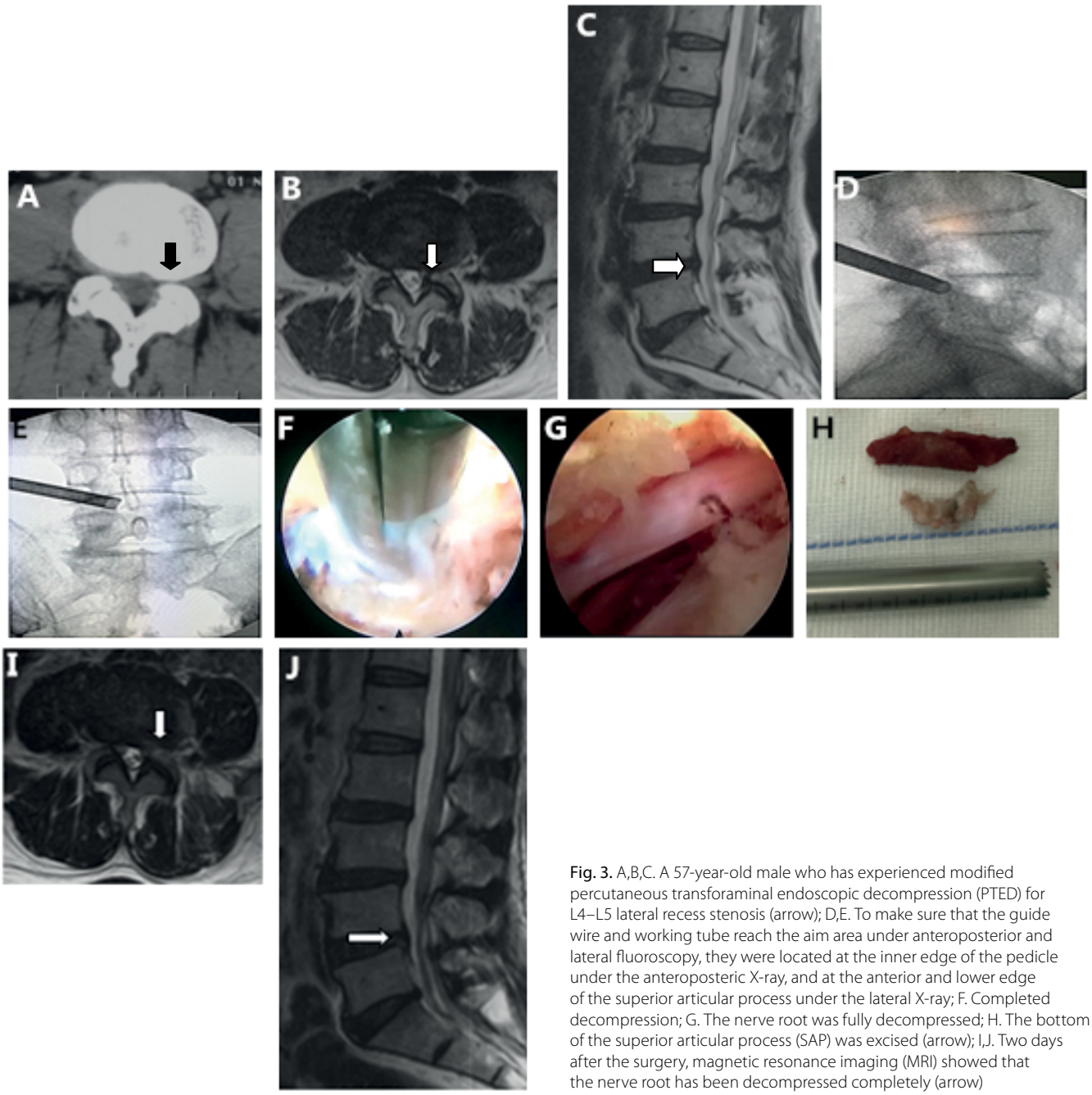

Fig. 3. A,B,C. A 57-year-old male who has experienced modified percutaneous transforaminal endoscopic decompression (PTED) for L4–L5 lateral recess stenosis (arrow); D,E. To make sure that the guide wire and working tube reach the aim area under anteroposterior and lateral fluoroscopy, they were located at the inner edge of the pedicle under the anteroposteric X-ray, and at the anterior and lower edge of the superior articular process under the lateral X-ray; F. Completed decompression; G. The nerve root was fully decompressed; H. The bottom of the superior articular process (SAP) was excised (arrow); I,J. Two days after the surgery, magnetic resonance imaging (MRI) showed that the nerve root has been decompressed completely (arrow)

were 96.30%. Seven days after the operation, 65 cases were excellent, 11 cases were good and 32 cases were fair; the excellent rate was 70.38%. The excellent and good rates at 1 month after the operation were significantly higher than at 7 days after the operation, and the difference was statistically significant ($p < 0.05$) (Table 3).

Discussion

Since Verbiest,[1] a Dutch neurosurgeon, first defined LSS in 1954, the international understanding of the definition and partition of the lateral region of the lumbar spinal canal has not been unified. Among them, experts such

Table 1. Baseline characteristics

Patient data	Modified PTED (n = 108)
Age	46.81 ±16.90
Gender	
male	58
female	50
Segment	
L2–L3	1
L3–L4	7
L4–L5	67
L5–S1	33
Operation time [min]	90.000 (80.000, 95.000)
Intraoperative bleeding volume [mL]	9.000 (7.000, 12.000)

PTED – percutaneous transforaminal endoscopic decompression.

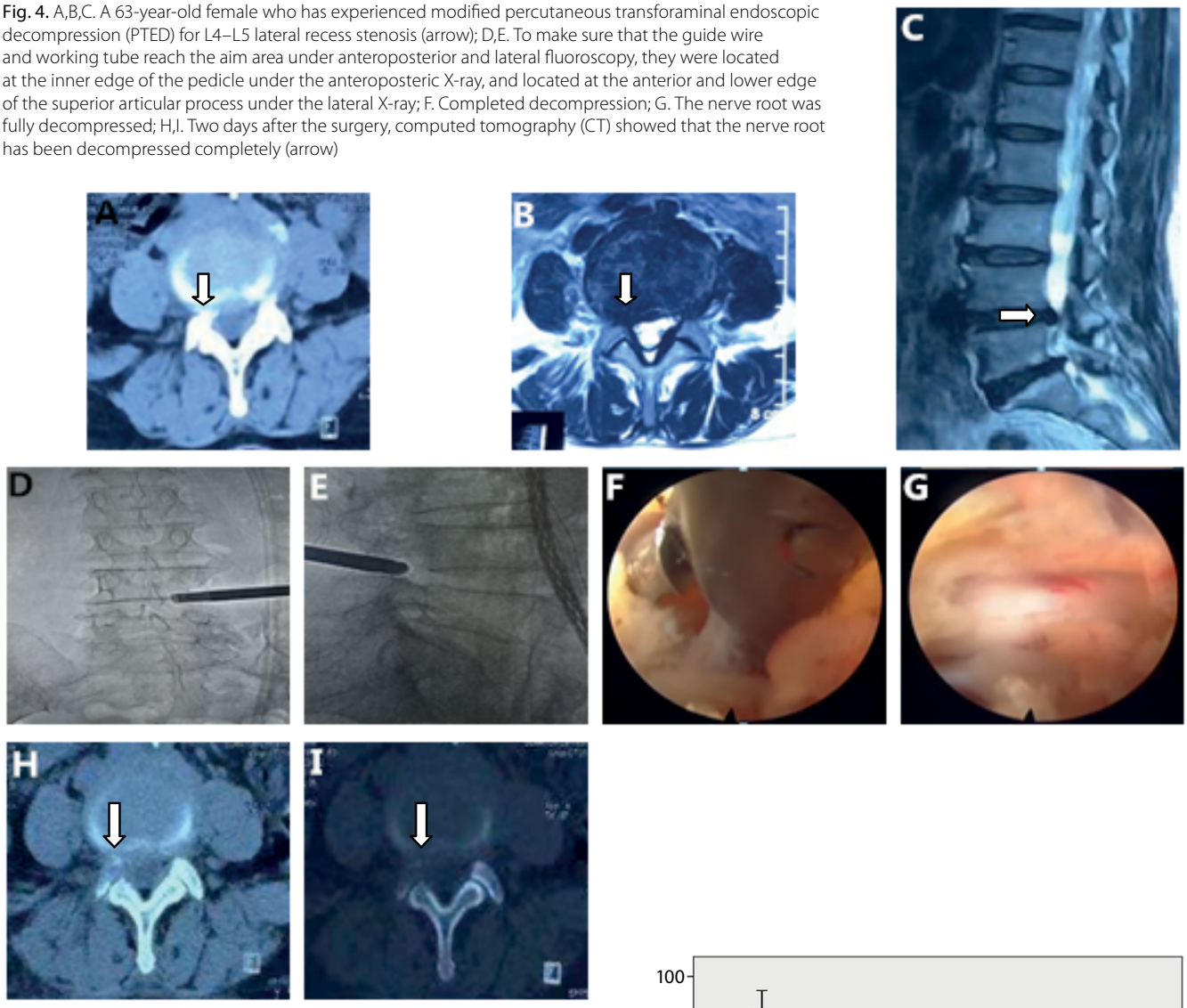

Fig. 4. A,B,C. A 63-year-old female who has experienced modified percutaneous transforaminal endoscopic decompression (PTED) for L4–L5 lateral recess stenosis (arrow); D,E. To make sure that the guide wire and working tube reach the aim area under anteroposterior and lateral fluoroscopy, they were located at the inner edge of the pedicle under the anteroposteric X-ray, and located at the anterior and lower edge of the superior articular process under the lateral X-ray; F. Completed decompression; G. The nerve root was fully decompressed; H,I. Two days after the surgery, computed tomography (CT) showed that the nerve root has been decompressed completely (arrow)

as Lee et al.[2] and Vital et al.[3] have proposed their views on the partition of lateral region of the lumbar spinal canal, and their concept became the most widely used partition basis: retrodiscal space, upper part of bony lateral recess, lower part of bony lateral recess, and intervertebral foramen. Regardless of the types, Mikhael et al.[4] defined LLRS as the sagittal diameter of the bony canal of LLR smaller than 3.0 mm or the diameter of soft tissue canal smaller than 1.0 mm.

The LLRS is often induced by sedentary work or fatigue, when the lumbar spine is overloaded, leading to the dehydration and denaturation of the intervertebral disc. This increases the stress of the tissue around the intervertebral disc, the range motion of the adjacent intervertebral joint, the hyperplasia and hypertrophy of ligament in lumbar spinal, and the formation of osteophyte. Finally, these pathological changes will eventually encroach LLR to reduce the diameter, resulting in nerve root compression and repeated friction by surrounding tissues, as well as nerve root ischemia and edema.[13] Therefore, patients with LLRS not only show varying

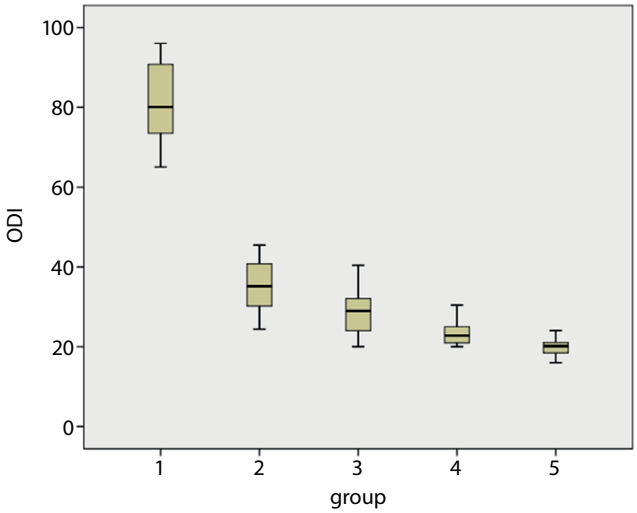

Fig. 5. Presentation of Oswestry Disability Index (ODI) value alteration before and after the operation (1 – before the operation; 2 – 1 day post operation; 3 – 7 days post operation; 4 – 1 month post operation; 5 – final follow-up). The M (Q_L, Q_U) of preoperative Oswestry Disability Index (ODI) score was 80.0700 (72.7500, 90.7800), while the values of this score 1 day after the operation, 7 days after the operation, 1 month after the operation, and at the final follow-up were 35.1300 (30.2100, 40.7800), 28.9950 (24.0400, 32.0600), 23.0200 (21.0000, 25.8525), and 20.1300 (18.4500, 21.0750), respectively

M – median; QL – lower quartile; QU – upper quartile.

Table 2. Comparison of back pain, leg pain, VAS and ODI before and after operation

Parameter	M (Q_L, Q_U)
ODI	
preoperative	80.070 (72.750, 90.780)
postoperative (1 day)	35.130 (30.210, 40.780)
postoperative (7 days)	28.995 (24.040, 32.060)
postoperative (1 month)	23.020 (21.000, 25.853)
postoperative (final follow-up)	20.130 (18.450, 21.075)
H	436.333
p-value	0.000*
VAS (back pain)	
preoperative	7.00 (6.00, 8.00)
postoperative (1 day)	3.00 (3.00, 4.00)
postoperative (7 days)	2.00 (2.00, 3.00)
postoperative (1 month)	2.00 (2.00, 3.00)
postoperative (final follow-up)	2.00 (2.00, 2.00)
H	351.958
p-value	0.000[&]
VAS (leg pain)	
preoperative	8.00 (7.00, 9.00)
postoperative (1 day)	3.00 (3.00, 4.00)
postoperative (7 days)	2.00 (2.00, 3.00)
postoperative (1 month)	2.00 (2.00, 2.00)
postoperative (final follow-up)	2.00 (2.00, 2.00)
H	370.405
p-value	0.000[#]

VAS – Visual Analog Scale; ODI – Oswestry Disability Index. * Kruskal–Wallis test results are as follows: H = 436.333, p < 0.001. According to the test standard α = 0.05, if H0 is rejected, ODI differences can be considered statistically significant before the surgery and after 1 day, 7 days, 1 month and at final follow-up (4 time nodes after the surgery). [&] Kruskal–Wallis test results are as follows: H = 351.958, p < 0.001. According to the test standard α = 0.05, if H0 is rejected, VAS (back pain) differences can be considered statistically significant before the surgery and after 1 day, 7 days, 1 month and at final follow-up (4 time nodes after the surgery). [#] Kruskal–Wallis test results are as follows: H = 370.405, p < 0.001. According to the test standard α = 0.05, if H0 is rejected, VAS (leg pain) differences can be considered statistically significant before the surgery and after 1 day, 7 days, 1 month and at final follow-up (4 time nodes after the surgery).

degrees of low back pain but also show lower limb pain, numbness and intermittent claudication caused by LLRS.

For LLRS, nonoperative treatment is ineffective, and surgery is often needed. The traditional treatment of LLRS has always been PLIF, because it provides a way to directly contact the diseased vertebral body, relieving waist and leg pain and other discomforts, mainly through decompression and fusion. However, the operation is traumatic and destroys much tissue structure around the lumbar vertebrae. With time, the incidence of complications related to surgery is high, contributing to an increasing risk of the perioperative surgery. There is also a risk of the implanted internal fixator to fracture, loosen, and other complications to appear.[14] The trend of surgical treatment has turned to minimally invasive surgery, and many experts and scholars have presented new solutions.[14,15]

In 1989, Schreiber et al. first applied the endoscopic technique to percutaneous nucleus pulposus removal.[10] With the updating endoscopic theory and equipment, TESSYS technique has been one of the most reliable minimally invasive spinal surgery techniques and is widely used

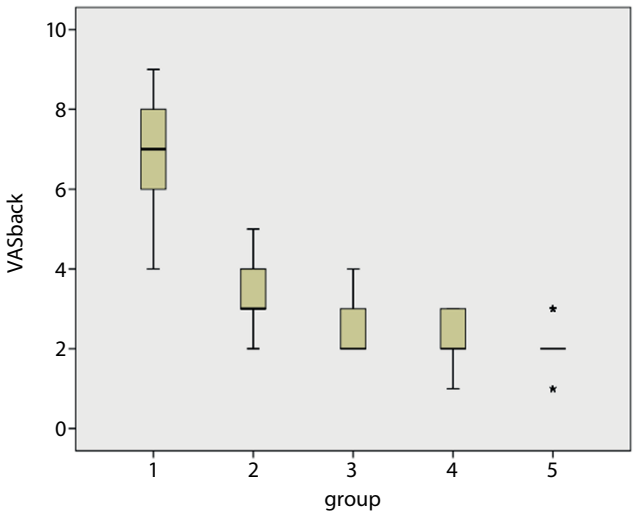

Fig. 6. Visual Analog Scale (VAS) for low back pain (VASback) value alteration before and after the operation (1 – before the operation; 2 – 1 day post operation; 3 – 7 days post operation; 4 – 1 month post operation; 5 – final follow-up). The M (Q_L, Q_U) of preoperative VASback was 7.00 (6.00, 8.00), while the values of this score 1 day after the operation, 7 days after the operation, 1 month after the operation, and at the final follow-up were 3.00 (3.00, 4.00), 2.00 (2.00, 3.00), 2.00 (2.00, 3.00), and 2.00 (2.00, 2.00), respectively

M – median; Q_L – lower quartile; Q_U – upper quartile.

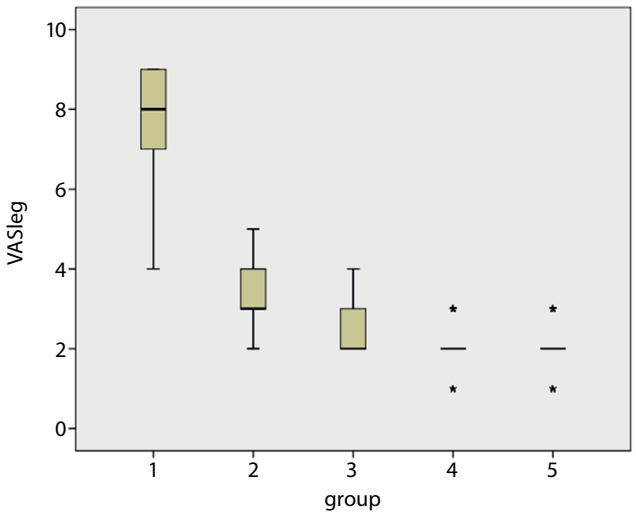

Fig. 7. Visual Analog Scale (VAS) for leg pain (VASleg) value alteration before and after operation (1 – before the operation; 2 – 1 day post operation; 3 – 7 days post operation; 4 – 1 month post operation; 5 – final follow-up). The M (Q_L, Q_U) of preoperative VASleg was 8.00 (7.00, 9.00), while the values of this score 1 day after the operation, 7 days after the operation, 1 month after the operation, and at the final follow-up were 3.00 (3.00, 4.00), 2.00 (2.00, 3.00), 2.00 (2.00, 2.00), and 2.00 (2.00, 2.00), respectively. In summary, it can be seen from the box plots of score that, except for the scores of individual research subjects which are quite different from those of others, the score values of almost all research subjects are getting closer and closer to each other, which can more intuitively express the effect of a surgical intervention

M – median; Q_L – lower quartile; Q_U – upper quartile.

in the clinic. Due to SAP being an obstacle to the working channel and the anterolateral dura mater, foraminoplasty by removing part of SAP is the key to TESSYS.

Table 3. Comparison of efficacy 7 days and 1 month after the operation (n (%))

Variable	Excellent	Good	Fair	Poor	Excellent rate
Postoperative efficacy (7 days)	65 (60.19)	11 (10.19)	32 (29.62)	0 (0.00)	76 (70.38)
Postoperative efficacy (1 month)	88 (81.48)	16 (14.82)	4 (3.70)	0 (0.00)	104 (96.30)
χ^2 value	–	–	–	–	26.13
p-value	–	–	–	–	<0.05

For TESSYS, the failure rate of nonforaminal surgery is as high as 60%.[16] The traditional TESSYS technique involves removing the tip of SAP. The TESSYS technique uses a multistage trephine outside the guide rod. The surgeon gradually resects the tip of the superior articular process under X-ray fluoroscopy, enlarges the intervertebral foramen, and sends the endoscope into the spinal canal. First, the herniation in the spinal canal is removed. Then, the intervertebral disc is cleaned. The TESSYS technique significantly improves the curative effect of percutaneous endoscopic surgery by intervertebral foramen approach and expands the surgical indications. Nevertheless, the surgery site is at the tip of the superior articular process, the space is narrow, the range of surgery is limited, and the treatment of contralateral recess stenosis is still unsatisfactory.[17] In the past, Yang et al. have proposed that the base had more advantages than the tip.[18] At the same time, Li et al.[19] improved the existing foraminoplasty and changed the position of the foraminoplasty from the tip of SAP to the bottom of SAP. Since the site of foraminoplasty is far away from the exiting nerve root, theoretically, the incidence of dysfunction is low.

Our technique is improved based on the TESSYS technique. The 7.6 mm-diameter trephine is used to shape the base of the articular process under the protection of the casing of the trephine. Consequently, there is sufficient room for shaping, far away from the exit nerve root to avoid its injury.[20] The modified TESSYS technique can directly enlarge the lateral recess, remove the cohesive osseous structure of the articular process, the hypertrophic ligamentum flavum and the protruding nucleus pulposus, and complete more effective nerve root decompression.

It is essential for LLRS patients to enlarge the width of the intervertebral foramen during PTED treatment.[21] Spinal foraminoplasty can completely decompress the ventral and dorsal structures by cutting the SAP base part and removing the intervertebral foraminal ligament to expand the orifice, contributing to visually displaying the epidural space. The tools currently used for foraminoplasty include endoscopic burr, multistage trephine, and reamers.[22–24] Most of the SAP is removed under the working channel endoscope to ensure the safety of the operation. Nonetheless, it is limited by the working channel, the foramina efficiency is low and the expansion of the lateral recess is restricted. Besides, the microscopic drill will release heat while in use, damaging the nerve roots and causing temporary nerve stimulation, postoperative sensory disturbance and iatrogenic injury.[25]

Compared with reamer and laser, the 7.6 mm-diameter trephine is an economical and time-saving device for abrading part of the SAP base under fluoroscopy guidance to perform foraminoplasty. Nevertheless, there is also the risk of damaging the SAP covering ligaments. Additionally, the working channel has enough space after cutting a part of the SAP. When using a trephine, perspective must be used in order to ensure an acceptable instrument angle and depth, and confirm that the trephine has penetrated the inner edge of the SAP. However, part of the nerve root in lateral recess stenosis is compressed by the hyperplastic osteophyte of the bony channel, and the risk of damaging the nerve root during decompression is extremely high. Therefore, the extensive surgical experience is required to fully control the trephine depth during vertebroplasty.[26] Moreover, several fluoroscopic examinations are required, increasing the exposure of patients and medical staff to radiation.[27]

The technical advantage of the surgical method used in this study is that the intervertebral foramen is located at the bottom of the SAP rather than at the tip of it. During the operation, the direction and angle of decompression can be flexibly adjusted according to the specific location of the nerve root canal stenosis. If the stenosis of the LLRS is on the inner side of the intervertebral foramina and the yellow space of the intervertebral disc, the medial part of the SAP is mainly removed; if the stenosis is biased to the bony recess, the bottom of the SAP is mainly removed. Meanwhile, the hypertrophy that hinders the operation of the surgical field can be removed. The ligamentum flavum and the posterior longitudinal ligament can also remove the hyperplastic osteophytes, and the decompression can be maximized to the back of the intervertebral disc.

The 108 patients in our study population had good postoperative results without related complications such as spinal instability, dural leakage and vascular nerve damage. The indexes of this group of patients 3 months and 2 days after operation were significantly better than those 1 day before the operation, indicating the statistically significant difference ($p \leq 0.05$). However, there was no significant difference between the 2 groups in the average of the indicators on the 2nd day after the surgery due to incision pain and soft tissue spasm ($p > 0.05$). Most patients felt apparent relief after the surgery. Regarding some patients with residual nerve symptoms, such as numbness and pain in the lower limbs, it is believed that the edema and inflammation

caused by the disturbance of the nerve roots appeared during the operation. Satisfactory results were obtained after 2–3 weeks of treatment with dehydration, low-dose hormones and non-steroidal anti-inflammatory drugs. Although there was a certain complication rate reported in the past, a certain treatment was given in time, such as rehabilitation physiotherapy, hormone shock, and others, and the follow-up treatment effect was satisfactory.

Limitations

There are some limitations that need to be acknowledged and addressed regarding the present study. The first one concerns the small number of study group. Although our approach might not have been optimal, it enabled us to objectively evaluate the effectiveness of PTED in patients with LLRS. Because the results of the study were very consistent and showed a small standard deviation, this study might have scientific meaning despite the small number of participants. Second, due to the heterogeneity of the surgical techniques used and the experience of the surgeons, the findings could not have been simply generalized beyond the study group.

Conclusion

To sum up, PTED (performed with the aid of 7.6 mm-diameter trephine) has a satisfactory clinical effect in the treatment of LLRS. The use of a 7.6 mm trephine for foraminoplasty can improve the efficiency of foraminoplasty without reducing the stability of the lumbar spine. The PTED (performed with the aid of 7.6 mm trephine) is one of the safe and effective surgical methods in the treatment of LLRS.

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