The short-term effectiveness of precise safety decompression via two-time percutaneous lumbar foraminoplasty (TPLF) and percutaneous endoscopic lumbar decompression (PELD) for lumbar lateral spinal canal (LLSC) stenosis

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Abstract

Purpose This prospective study reports a new technique: precise safety decompression via two-time percutaneous lumbar foraminoplasty (TPLF) and percutaneous endoscopic lumbar decompression (PELD) for lumbar lateral spinal canal (LLSC) stenosis, and short-term clinical outcomes.

Methods 69 patients with single-level LLSC stenosis simultaneously occurred in both zone 1 and 2 who underwent TPLF-PELD from November 2018 to April 2019 were prospectively analyzed. Clinical outcomes were evaluated according to preoperative, 3 months postoperatively and last follow-up via leg pain/low back pain (LBP) visual analogue scale (VAS) scores, Oswestry disability index (ODI) scores and the Macnab criteria. The postoperative MRI and CT were used to confirm the complete decompression and flexion-extension X-Ray in last follow-up were used to observe lumbar stability.

Results All patients successfully underwent TPLF-PELD and the stenosis was completely decompressed confirmed by post-operative MRI and CT. The mean follow-up duration was 13 months (range, 8-17 months). The mean preoperative leg pain VAS score is 7.05±1.04 (range 5-9), which decreased to 1.03±0.79(range 0-3) at third month postoperatively and to 0.75±0.63 (range 0-2) by the last follow-up visit. The mean preoperative ODI was 69.8±9.05 (range, 52-85), which decreased to 20.3±5.52 (range, 10-35) at the third month postoperatively and to 19.6±5.21 (range, 10-34) by the last follow-up visit. The satisfactory (excellent or good) results were 94.2%. There was 1 patients with aggravated symptoms which relieved after open surgery. 2 patients with dural tear and 2 patients with postoperative LBP. No recurrence and segmental instability was observed in the last follow-up.

Conclusion TPLF-PELD could be a good alternative option for the treatment of LLSC stenosis patients whose stenotic region occurred in both zone 1 and 2.

Introduction

Along with the aging of the society, the incidence of degenerative lumbar disorder has increased, and it has become one of the main causes of lumbar surgery in elderly patients[1, 2]. Owing to the remarkable evolution of percutaneous endoscopic lumbar decompression (PELD), the application of spinal endoscopy is shifting from the treatment of soft disc herniation to complex lumbar spinal stenosis. Satisfactory rate of PELD in treating lumbar spinal stenosis (LSS) are reported at 82–92%[3].

It has been widely accepted LSS anatomically involved the central canal, lateral recess, foramen or any combination of these locations[4, 5]. However, the concept lateral recess still have no universal definition and was frequently represented by other ambiguous terms, such as radicular canal, lateral recess zone or nerve root canal[6, 5, 7]. After carefully analyzed the spinal anatomy and clinical facts, our team recently redefined the concept “lateral lumbar spinal canal (LLSC)” and creatively provided a new classification of LLSC with five different zones[8]. We found retrodiscal space (zone 1) and upper bony lateral recess (zone 2) were the two most common regions for occurrence of lumbar degeneration. In clinical practice, stenosis simultaneously occurs in both zone 1 and 2 were most common (43.4%)[8]. Unfortunately, endoscopic decompression for this kind of patients was difficult even for experienced endoscopic spine surgeons, because the complicated compressive situation.

Percutaneous endoscopic lumbar foraminoplasty (PELF) was initially used to enlarge the foramen by trephine and/or high-speed drill. Thereafter, foraminoplasty was used as an efficient decompressive method when treating lumbar spinal stenosis[9, 3]. The procedure of foraminoplasty was facilitated by changing the specific location of the needle tip and trajectory of trephine to decompress different compressive pathology. Foraminoplasty was performed to resected the upper-ventral part of superior articular process (SAP) in classical TESSYS technique [10]. However, the removed scale was not enough for both zone 1 and 2 involved stenosis patients, additional endoscopic dorsal decompression was needed by using high-speed drill during operation. The disadvantages were obvious: the increased surgery time, additional risk of iatrogenic nerve root/dural sac injury and, most importantly, post-operative low back pain (LBP) and potentially spinal instability caused by excessive removal of SAP.

To realize accurate decompression and minimize the destruction of facet joints. We creatively applied the accurate two-time percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar decompression (TPLF-PELD) by separately removing upper-medial-ventral part of facet joint and lower medial-ventral part of SAP for both zone 1 and 2 involved stenosis patients. In our previous retrospective study in 2016, 29 patients achieved the satisfactory clinical outcomes with the excellent and good rate of 93.3% by using the innovative technique[11]. The present study was prospectively designed to reevaluated the clinical outcomes of recent similar patients by using TPLF-PELD with the help of our specially designed depth-limited instruments. Technique notes and short-term outcomes are included in this report.

Materials And Methods

This prospective study was approved by the Ethics Committee of West China Hospital, Sichuan University and was registered with the Chinese Clinical Trial Registry (ChiCTR1800019551). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to surgery.

69 patients with single-level LLSC stenosis simultaneously occurred in both zone 1 and 2 from November 2018 to April 2019 were enrolled. All of the patients were performed with TPLF-PELD by one endoscopic spine surgeon (KQQ). The characteristics of 69 patients are shown in Table 1. LBP occurred in 5 patients (7.2%), muscle weakness of the lower limbs in 1 patients (1.4%), extremity radiating pain with/without gluteal pain in 62 patients (89.8%) and neurogenic intermittent claudication in 53 patients (76.8%). All patients have no operation history.

Table 1
characteristics of patients undergoing accurate two-time percutaneous lumbar foraminoplasty (TPLF) and percutaneous endoscopic lumbar decompression (PELD)

Patient data	
Age at presentation, yrs	66.1 ± 7.5*(range, 42–91 years)
Male gender	40 (57.9%)
Occupation	
Sedentary	18 (26.1%)
Light work	30 (43.4%)
Heavy manual work	21 (30.5%)
Duration of symptoms, mo	20.9 ± 5.6* (range, 4–90 months)
Level of involvement	
L3/4	0 (0%)
L4/5	57 (82.6%)
L5/S1	12 (17.4%)
Side of LLSC stenosis	
left	39 (56.5%)
right	30 (43.5%)
Patients with comorbidities	
Diabetes mellitus	27 (39.1%)
Smoking	24 (34.8%)
Alcohol consumption	12 (17.4%)
Osteoporosis	22 (31.8%)
Hypertension	27 (39.1%)
Use of antidepressants	1 (1.4%)
Physical treatment and medications	
Steroid intake	19 (27.5%)
Nerve blocks/epidural blocks	11 (15.9%)
*Data represented as mean (± standard deviation)	

Included for study were patients who (1) manifested as single nerve root symptom, such as single side extremity pain, numb or weakness, with or without LBP. (2) with full preoperative radiological information. The method of distinguishing stenotic zone has been described in previous study (Fig. 1)[8]. Stenosis in zone 1 was diagnosed by sagittal T2-weighted MRI scans through paracentral region: the anteroposterior distance less than 1 mm. Stenosis in zone 2 was diagnosed by axial bone window CT scans: the anteroposterior distance in lateral recess region less than 3 mm. The radiological diagnosis should be identical to clinical symptom. Preoperative blocking of the nerve root could be applied in some intractable cases. (3) with obvious symptom (preoperative leg pain Visual Analogue Score (VAS) score over 6) after over 3 months' invalid conservative treatment. (4) was informed consent for our study and agreed to accomplish all follow-up.

Excluded for study were patients who (1) have lumbar segmental instability indicated by preoperative lumbar flexion-extension X-Ray. (2) combined with lumbar central canal stenosis. (3) was diagnosed as pure lumbar disc herniation. (4) high-grade lumbar spondylolisthesis with multi-level spinal stenosis. (5) with high iliac crest, the peak of iliac crest exceed lower quarter of L4 vertebral body, which hindered puncture in L5/S1. (6) with surgical contraindication.

Special Surgical Tools

Specially designed Depth-Limited Trephine for foraminoplasty by ourselves (ZL 201621149959.2)[12]: consist of trephine, handle and stopper (Fig. 2). The saw tooth of the trephine has no difference with traditional trephine. The diameter of trephine has different sizes: 6.5 mm, 7.5 mm and 10 mm. But the total length of the trephine is same: 243 mm. In the proximal end of the trephine, 17 circular grooves are designed. The first groove is 165 mm away from the distal end of trephine and there's the interval of 2 mm in the next adjacent grooves. The depth of foraminoplasty was accurately controlled and limited by the stopper located in the trailing end of the trephine. The stopper is locked in one of the grooves, and then the trephine cannot advance. The exact foraminoplasty depth we need can be adjusted by the location of the stopper. The handle can be easily assembled and unassembled from the trephine.

Surgical Techniques

All TPLF-PELD procedures employed by the author were essentially a classic Thessys technique popularized by Hoogland[9]. The procedures were performed under local anesthesia in the prone position on a radiolucent table using C-arm fluoroscopy. An 1.6 mm Spinal Guiding Cannulas (SPINENDOS, Germany) was inserted into the safe zone of Kambin's triangle. The puncture point were 12 ± 2 cm from midline according to the size of body and surgical level, 2–5 cm from horizontal line of target intervertebral disc. After infiltrating 15–20 ml of 0.5% lidocaine in the subcutaneous soft tissue, around SAP and intervertebral foramen, the needle was replaced with a 0.7-mm-diameter guiding wire. A Dilator 2-channels (7.0, 6.3 or 5.3 mm-diameter) was passed over the guiding wire under fluoroscopic control. Trephine Protection Tube (6.5, 7.5 or 8.5-mm-diameter) were introduced over the obturator until it was placed in proper position. The Depth-Limited Trephine designed by ourselves(6.5, 7.5 or 8.5-mm-diameter, selected based on pathologic condition) was used to perform two-time foraminoplasty, which was facilitated by changing the trajectory of trephine to aim for the different compressive portion. The details of the two foraminoplasty procedures are shown in Table 2, Fig. 3.

Table 2
Details of the two foraminoplasty procedure

	Target region	The inclination of the trephine		Removed section	The depth of foraminoplasty
		In lateral view	In AP view		
The first foraminoplasty	Retrodiscal space (Zone 1)	From the tip of superior articular process (SAP) to the posterior rim of the upper endplate of distal vertebral	From the tip of SAP to midpoint of upper endplate of distal vertebral body	Upper-medial-ventral part of facet joint which comprise tip and upper-ventral part of SAP, a part of inferior articular process (IAP) and a small ventral part of laminar.	Limited to 10–12 mm controlled by the special designed trephine
The second foraminoplasty	Upper bony lateral recess (zone 2)	From the tip of SAP to the cross-point of middle pedicular line and the posterior surface of vertebral body	From the tip of SAP to midpoint of middle pedicular line	Lower medial-ventral part of SAP	Limited to 12–14 mm controlled by the special designed trephine

In the first foraminoplasty, the scale of the resection can be slightly adjusted based on different pathologic conditions. After the first foraminoplasty, radiofrequency probe was endoscopically used (Working Tube With Elevator Tip, ID 7.2 mm, OD 8.0 mm, L178 mm; Spinal Endoscope, 30° direction of view, WC 3.75 mm OD 6.3 mm, WL 181 mm) to control bleeding and adequate exposure bony structures by resecting adherent soft tissue. The margin of exposure should from upper-ventral surface of SAP to lower-ventral surface of SAP and upper surface of pedicle. And then, a 1.5 mm Kirschner wire was knocked in the aiming site. After take out the Spinal endoscope, the second foraminoplasty was then performed after positioning the Trephine Protection Tube over the Kirschner wire and adjusting its tip embracing the ventral-basial part of SAP. In some sever stenosis cases, in order to preventing injuring nerve roots, we only entered the trephine into three quarters of SAP and break the involved SAP instead of completely resecting by trephine. For the two foraminoplasty procedures, the trephine need to be underdraught aiming to resecting more SAP.

After that, the Trephine Protection Tube was replaced with the Working Tube With Elevator Tip. And then, high-speed drilling was used to resect remaining hypertrophied SAP or IAP if needed. The Working Tube was adjusted to find and convenient for completely remove decompressive factors: the hypertrophied ligamentum flavum, facet joints and anterior herniated disc. To reduce the recurrence rate of lumbar disc herniation (LDH), we did not perform discectomy (only decompress dorsal compressive factors) for patients whose annulus was not damaged. The compressed nerve root was decompressed and explored from the distal-end to near-end, especially for the attachment point of annulus. The surgeon can see and mobilize both the traversing nerve root and exiting nerve root under endoscopic visualization. Free movement of dural sac and nerve root can be a sign of complete decompression. Epidural bleeding was controlled with a radiofrequency probe under saline irrigation.

Each operation duration, times of intraoperative C-arm fluoroscopy use and complication were recorded. Every patients were asked to wear lumbar protection devices for 2–4 weeks after the operation and to take muscle function exercise in 2 weeks after the operation.

Outcome Assessment

Outcomes were evaluated by follow-up interviews (WY) at 3 months and final follow-up after surgery. We used LBP and leg pain VAS and Oswestry disability index (ODI) to evaluate the outcomes of surgery. Function outcomes were assessed by using the modified Macnab criteria[13]. All patients routinely undergo 3D-reconstructive CT scans in 2 days after the operation, undergo MRI and CT scans in 3 months to confirm the complete decompression. In the final follow-up, patients undergo CT to confirm the no recurrence of LLSC stenosis, and flexion-extension X-Ray to observe lumbar stability. All postoperative radiological exams are permitted to be discharged.

Statistical analysis

Statistical analysis were performed with SPSS 23 software(SPSS Inc., Chicago, IL). Preoperative and postoperative (3 month and final follow-up) VAS and ODI scores were analyzed with ANOVA. $P < 0.05$ was considered as significant.

Results

Clinical outcomes

All patients successfully underwent TPLF-PELD without hematomas formation, change to open surgery or any nerve root injuries. Leg pain was immediately eased after the operation. The mean follow-up period was 13 months (range, 8–17 months).All clinical outcome results are shown in Table 3. 2 patients were complicated with dural tear that was all sever stenosis who was cured after conservative treatment without residual symptoms. There was 1 patient whose preoperative symptom did not relieve after the surgery. The postoperative CT scan illustrated a small separated bony segment moved into the spinal canal. After 2 month's conservative treatment, the symptom aggravated and we performed open surgery. The symptom completely disappeared immediately. 2 patients appeared moderate postoperative LBP without lumbar muscle weakness which disappeared after conservative treatment. All 3-months' postoperative MRI and CT confirmed compressive factors were completely removed and flexion-extension X-Ray and CT in final follow-up indicated no recurrence or lumbar segmental instability occurred.

Table 3
clinical outcomes of patients with precise safety decompression via accurate two-time percutaneous lumbar foraminoplasty (TPLF) and percutaneous endoscopic lumbar decompression (PELD)

The mean operative duration time, min	**63.2 (range, 30–110 min)**	
the mean times of intraoperative C-arm fluoroscopy use	13.8 (range, 5–41)	
VAS (leg pain/LBP)	**Mean (SD)**	**Significance level**
Pre op	7.05 ± 1.04/1.34 ± 0.48	
Post-op 3 mo	1.03 ± 0.79/1.02 ± 0.28	P < 0.05*/ P > 0.05
Final follow-up	0.75 ± 0.63/0.93 ± 0.31	
ODI	**Mean (SD)**	**Significance level**
Pre op	69.8 ± 9.05	
Post-op 3 mo	20.3 ± 5.52	P < 0.05*
Final follow-up	19.6 ± 5.21	
Subjective outcomes**		
Excellent	49	
Good	16	
Fair	3	
Poor	1	
Satisfactory (excellent or good) results	65/69 (94.2%)	
*Paired Student test. **Macnab criteria.		

Case Presentation

A 55-year-old male patient complained of severe left radicular pain for 12 months. He could not walk for 3 months because of severe left buttock and leg pain. Left L4/5 LLSC stenosis in both zone 1 and 2 was confirmed. We confirmed the totally decompression by postoperative CT and MRI. The leg pain was relieved immediately after the operation. No lumbar instability were indicated in the final follow-up (Fig. 4).

Discussion

“Lateral lumbar spinal canal” was first introduced by Lee in 1988 and was divided into entrance, mid and exit zones[5]. However, we also found the problems, such as ambiguous borders of each zones and improper names[14]. Before we first systemically defined the LLSC and provided classification, there’s no universal accepted definition of LLSC including lateral recess region[8]. We found that the retrodiscal space (zone 1) and upper bony lateral recess (zone 2) are the two most common regions the lumbar degenerative changes occurs. As we analyzed[15], zone 1 is surrounded by soft tissue whose dorsal compressive element was ligamentum flavums and joint capsules; zone 2 was formed by tricortical bony structures whose compressive element was hypertrophied SAP. Consequently, no matter the lumbar spinal stenosis occurred in zone 1 and/or 2, to ensure the effectiveness of surgery, accurate and complete surgical decompression is important. However, for LLSC stenosis patients involving both zone 1 and 2, surgical complete decompression raises higher requirements. Conventional open surgery can well treated LLSC stenosis patients by resecting laminectomy and medial arthrotomy, however, the drawback was also obvious: more operation time, more recovery period and more complication[16].

PELD had been greatly developed and made a revolutionary progress in recent years[17–19]. The application of foraminoplasty greatly expanded the indication of PELD in treating lumbar spinal stenosis. [3, 20, 21]. Various foraminoplasty methods are available by adjusting the location of needle tip and trajectory of trephines, achieving the purpose of decompression on specific targets. For instance, classical TESSYS technique popularized by Hooglan et al. first introduced the foraminoplasty procedure by resecting the upper-ventral part of the SAP[22]; afterwards, variation of the TESSYS technique was created aiming to removal of lower-ventral part of hypertrophied SAP in lateral recess stenosis patients[9, 23]; recently, our team created trans-articular and trans-isthmus approaches foraminoplasty methods to treat central/paracentral and high up-migrated lumbar disc herniation patients, respectively[12, 24].

However, endoscopic decompression towards zone 1 and 2 required different foraminoplasty targets (Fig. 3). It was very difficult to realize full-course decompression via single foraminoplasty in classical TESSYS technique without the help of endoscopic high-speed drill. The frequent usage of high-speed drill bound to cause additional duration of surgery, higher risk of iatrogenic nerve root/dural sac injury and excessive resection of SAP which can cause potential postoperative LBP and lumbar segmental instability[3]. Therefore, after careful analyzing the anatomical, pathological and biomechanical features of LLSC mentioned in the published study[8] and combining with extensive endoscopic surgery practice, we creatively designed precise safety decompression via TPLF-PELD which performed programmed and accurate foraminoplasty toward zone 1 and 2 separately. The advantages were obvious. On the one hand, the programmed operation greatly improved decompression efficiency and accuracy. This guaranteed the full-course and complete decompression of the two regions with a shorter time. On the other hand, more normal SAP can be retained because most principle compression in zone 1 and 2 would be accurately resected in the two-time programmed foraminoplasty procedures. This can largely prevented occurrence of the postoperative LBP and potential lumbar segmental instability.

Of the 69 included patients, preoperative leg pain VAS score was 7.05 ± 1.04 which decreased to 1.03 ± 0.79 postoperatively ($p<0.05$). Besides, we did not find the increasing postoperative LBP VAS score in our group ($p>0.05$). This indicates our new technique was not necessarily increase iatrogenic postoperative LBP which was another beneficial comparing to conventional open surgery. We owing to the advantages of reduced damage of facet joints. The final follow-up excellent and good rates were 94.2% which was similar to conventional microsurgical technique[25] and was higher than other endoscopic technique: 82% in Kambin[26], 85% in Lewandrowski[23] and 89.2% in Yeung[27]. No incomplete decompression, nerve root injury or other complication appeared. No recurrence and segmental instability was observed in any patient during the follow-up period. We believed the good clinical outcome owed to using the classification confirming compressive factor preoperatively and using TPLF-PELD realizing full-course, complete decompression and avoiding unnecessary resection of SAP intraoperatively. Besides, our special designed depth-limited trephine effectively guaranteed the safety of the procedures. For those sever stenosis patients, the nerve root was tightly compressed by hypertrophied facet joint. The nerve root may be easily injured by excessive advance of trephine without depth limitation.

Among all 69 patients, only one patients occurred sever postoperative complication with small separated bony material leaved over in the spinal canal which was finally took out by open surgery after 2 months. This was caused by insufficient experience in the early period. Besides, there were 2 intraoperative dural tear which be cured by conservative treatment. We attributed it to the severe adhesion between dural sac and surrounding bony structures caused by long-term stenotic changes. The complication rate was 4.3% which apparently lower than others ranging from 5.5%-13.2%[9, 26, 27]. The above-mentioned results proved the effectiveness and rationality of the TPLF-PELD in treating LLSC stenosis in both zone 1 and 2.

We also concerned about the effect on postoperative lumbar segmental stability after the removal of a part of facet joint. Although it has been demonstrated that facetectomy decreases the stiffness and increases the mobility of the spinal motion segment in all modes of loading[28, 29], there is still no evidence that injured or damaged facet joints consequently induce the mechanical instability of the spine[30]. What’s more, our technique only resect a small part of facet joint, about less than 10–20% of the whole facet joint. Osman studied the pathoanatomic and flexibility changes after posterior and transforaminal decompression in a cadaver biomechanical study[31], which even much more than ours. No flexibility change and instability was noted, the same as our previous reports[15, 12, 24, 11]. In our study, we designed lumbar dynamic position X-ray in each patient in final follow-up. No postoperative iatrogenic segmental instability was observed.

The limitations of this study should be noted. In particular, the small sample size and a short follow-up period. However, the aim of the study was to introduce an alternative approach for treating LLSC stenosis in both zone 1 and 2 rather than to compare it with other methods. In addition, TPLF-PELD has a steep learning curve and relative narrow indication: the surgery only suited to simple single-level LLSC stenosis patients in both zone 1 and 2. The qualified patients number was limited and further study in the future was needed.

Conclusion

TPLF-PELD is a minimal-invasive, effective and safe surgical method that can well treat LLSC stenosis patients whose stenotic region occurred in both zone 1 and 2 with the advantages of less lumbar structure damaged, lower complication rate and good short-term clinical outcome.

Declarations

Compliance with ethical standards

Conflict of interest All authors declare no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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Figures

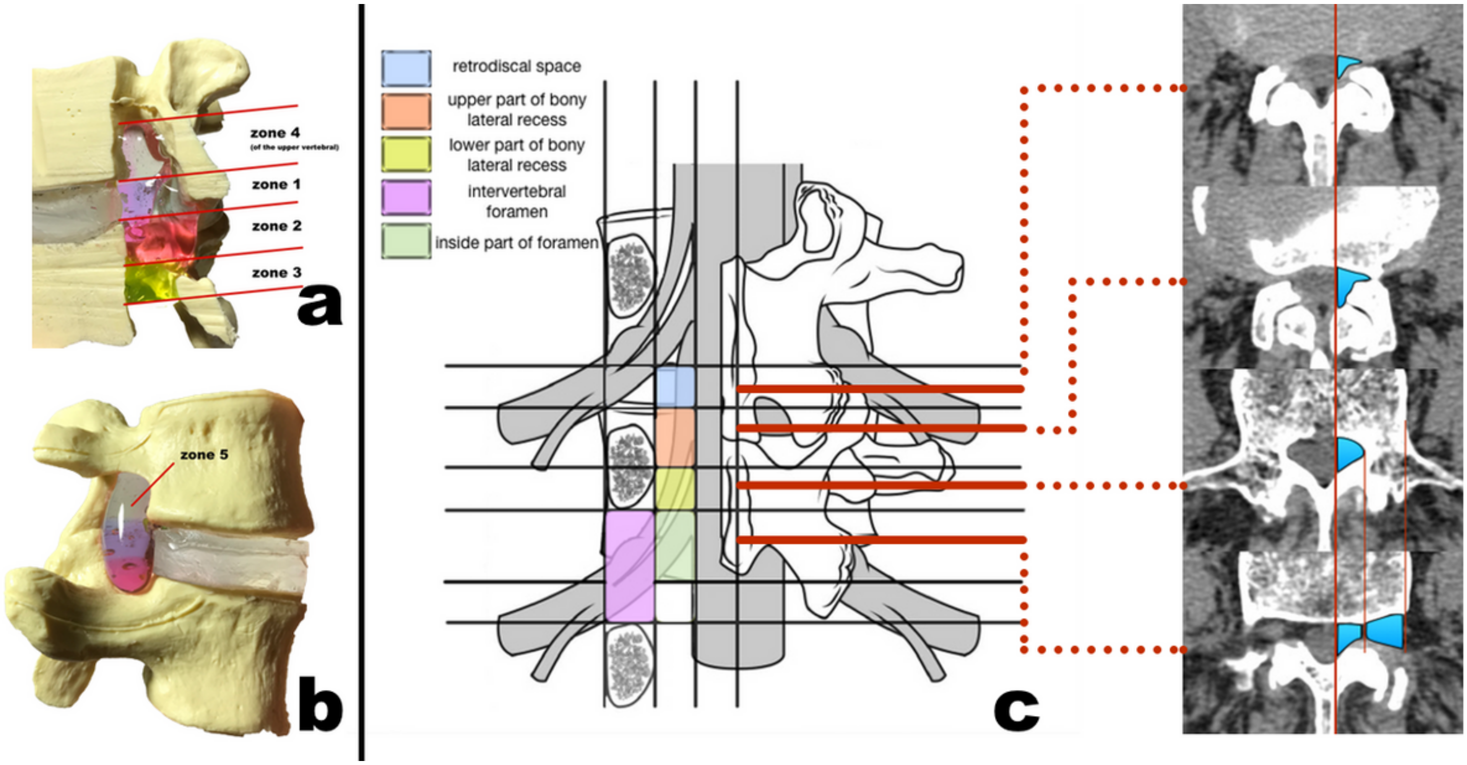

Figure 1

Five zones of lateral lumbar spinal canal (LLSC) divided by accurate boundaries. a,b Different zones shown in artificial model in medial and lateral views. c schematic diagram of five zones. The boundaries of each zones were described in the text. The right four axial CT scanning image shows the different views of cross-sections (the red solid lines) and the labelled regions correspond with each zones.

Figure 2

Picture of the specially designed depth-limited trephine.

Figure 3

a, b Schematic diagram of the inclination of the trephine trajectory in lateral and AP view in the first foraminoplasty. c, d Schematic diagram of the inclination of the trephine trajectory in lateral and AP view in the second foraminoplasty. The cross point of the white solid line was described in the text. e schematic diagram of the two-time percutaneous lumbar foraminoplasty procedure.

Figure 4

a, b Preoperative X-ray in AP and lateral view. c Preoperative sagittal CT scans indicated stenosis of retrodiscal space (zone 1) in left L4/5 (red circle). d Preoperative axial CT scans indicated upper bony lateral recess (zone 2) stenosis in left L4/5 (red circle). e, f Preoperative sagittal and axial T2-weighted MRI scans showed L4/5 left zone 1 stenosis caused by lumbar disc bulge anteriorly and hypertrophied, curled ligamentum flavum posteriorly (red circle). g, h Fluoroscopy during operation shows the trajectory of the trephine in the first foraminoplasty in AP and lateral views. i, j Fluoroscopy during operation shows the trajectory of the trephine in the second foraminoplasty in AP and lateral views. k, l Three months postoperative sagittal and axial CT bony-window scans clearly indicates complete decompression of zone 1 and 2. m, n Three months postoperative sagittal and axial T2-weighted MRI scans shows the nerve root was decompressed without recurrence. o, p Postoperative flexion-extension X-Ray in final follow-up indicated that no lumbar instability occurred.