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Cohort Study

# Modified Percutaneous Lumbar Foraminoplasty and Percutaneous Endoscopic Lumbar Discectomy: Instrument Design, Technique Notes, and 5 Years Follow-up

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**Background:** Conventional percutaneous endoscopic lumbar discectomy (PELD) with an "inside-outside" technique has 4.3% – 10.3% surgical failure rate, especially in central herniated discs (HDs), migrated HDs, and axillary type HDs. PELD with foraminoplasty has been used for complex HDs. Percutaneous lumbar foraminoplasty (PLF), which is performed with a trephine or bone reamer introduced over a guidewire without a protective working cannula in the original Tessys technique, can quickly cut the hypertrophied bony structure under fluoroscopic guidance, and risk injury to the exiting and traversing nerve roots.

**Study Design:** A prospective cohort study.

**Setting:** Hospital and outpatient surgical center.

**Objective:** To evaluate the outcome and safety of modified PLF-PELD with a specially designed instrument for complex uncontained lumbar HDs.

**Method:** From April of 2007 to April of 2009, 148 patients with uncontained lumbar HDs were treated with modified PLF-PELD. Magnetic resonance imaging (MRI) checkup was performed the next morning after the operation. Outcomes of symptoms were evaluated by follow-up interviews at 3 months, 6 months, one year, and 5 years after surgery. Low back pain and leg pain were measured by visual analog scale (VAS) score (1 – 100). Functional outcomes were assessed by using the Oswestry Disability Index (ODI) and modified MacNab criteria.

**Result:** Follow-up data were obtained from 134 cases, including 14 cases on L3-4, 78 cases on L4-5, and 42 cases on L5-S1. One hundred-eight cases were prolapse type, while 26 cases were sequestration type. Pre-operative symptoms and deficits included nerve root dermatome hypoesthesia in 98 patients (73%), nerve root myotome muscle weakness in 32 patients (23%), and weakening or disappearance of tendon reflex in 43 patients (32%). No case required conversion to an open procedure during the surgery. Low back pain and leg pain were significantly relieved immediately after surgery in all patients. MRI examination showed adequate removal of HD in all patients. VAS scores and ODI values were significantly lower at all time points after surgery than before surgery. The percentage of pain relief in leg pain was significantly higher than that in low back pain ($P < 0.01$). But there was no significant correlation between duration of the preoperative symptoms and the percentage of pain relief. MacNab scores at 5 years after surgery were obtained from 134 patients. Seventy-five cases were rated "excellent"; 49 were rated "good," Five patients experienced heavier low back pain, thus being classified as "fair." Five cases with recurrence were rated "poor." Preoperative and postoperative (5 years follow-up) related nerve root function status was compared. Sensation and muscle strength recovered significantly ($P < 0.01$), while tendon reflex was not changed ($P = 0.782$). No patients had infections. Five patients were complicated with dysesthesia in distribution of the exiting nerve that was all operated at L5-S1. Complaints were reduced one week after treatment with medium frequency pulse electrotherapy. Five cases required a revision surgery after recurrence.

**Limitations:** This is an observational clinical case series study without comparison.

**Conclusion:** Modified PLF-PELD with a specially designed instrument is a less invasive, effective and safe surgery for complex uncontained lumbar DH.

**Key words:** Lumbar disc herniation, minimally invasive treatment, foraminoplasty, percutaneous endoscopic lumbar discectomy

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Percutaneous endoscopic lumbar discectomy (PELD) is a minimally invasive spinal technique that has several advantages over open discectomy, including less paravertebral muscle injury, preservation of posterior ligamentous and bony structure, less postoperative instability, facet arthropathy, and disc space narrowing, and rapid recovery. Also, there is no interference of the epidural venous system that may lead to chronic neural edema and fibrosis (1,2). Epidural scarring after open discectomy, a common occurrence, which leads to clinical symptoms in more than 10% of patients (3,4), is not observed in PELD. PELD has gained popularity for the removal of herniated disc (HD) material over the past few years since Kambin (5) reported the results of arthroscopic microdiscectomy through the posterolateral approach in 1992. Despite the remarkable evolution of endoscopic techniques and instrumentation leading to successful outcomes comparable to conventional open surgery, surgeons still have some difficulty with PELD. Most concerns are about the incomplete removal of disc fragments, a steep learning curve, recurrence, and radiation exposure (6-8). Conventional PELD with the "inside-outside" technique has a 4.3% – 10.3% surgical failure rate, especially in central HDs, migrated HDs, and axillary type HDs (9,10). PELD with foraminoplasty has been used for complex HDs (11-14). Foraminoplasty was defined as "widening of the foramen by undercutting of ventral part of the superior articular process (SAP) with ablation of the foraminal ligament, using bone trephines or an endoscopic drill and side-firing laser to visualize the anterior epidural space and its contents" (11).

Undercutting of the SAP can be done with the help of an endoscopic round diamond burr, side-firing laser, trephine, or reamers, etc. Endoscopic visualization during drilling avoids injury to important structures in the foramen and allows removal of only enough bone to access the ruptured fragment. But endoscopic foraminoplasty with tiny tools is a time-consuming procedure without causing significant increase in the size of lateral recess because of the restriction of the working channel of the rigid endoscope (11,12,15,16). In cases combined with lateral recess stenosis, retrieval of a highly migrated herniation can be technically very challenging even for an experienced surgeon. Down-migrated herniation invading the axilla between the traversing nerve root and the dural sac also pose a lot of difficulty (11,12). Lewandrowski (12) also reported clinical failures that occurred in patients with bony stenosis in the lateral recess and entry zone of the neuroforamen. Besides, the increase in temperature while using a high-speed burr or side-firing laser may potentially lead to inflammation of the nerve and may also cause deterioration of nerve conduction to some extent (15,16). Knight et al (17) reported that transient post-operative "flares" were noted in 19% of patients when a side-fire laser was used in transforaminal endoscopic lumbar foraminoplasty for foraminal stenosis, while Ahn et al (18) reported 6.1% postoperative dysesthesia after endoscopic foraminotomy with an endoscopic high-speed drill. The disadvantages of endoscopic foraminoplasty also include a steep learning curve and need of expensive equipment.

A trephine or bone reamer can quickly cut off the hypertrophied SAP or osteophyte under fluoroscopic guidance. It is more efficient and time saving than endoscopic foraminoplasty. The original Tessys technique described by Schubert and Hoogland (19) advocates the use of transforaminal percutaneous reamers and drills to the tip of the SAP, which are introduced over a guidewire without a protective working cannula. They carry the risk of injury to the exiting and traversing nerve root, which may produce dysethetic leg pain and neurological dysfunction in the affected extremity. Also, a bone reamer can easily remove the tip of the process; however, the horizontal part of the SAP and lateral recess medial to the pedicle is relatively difficult to remove because this part is thick and hard (20). To address the issues of the existing methods, we invented a specially designed instrument for percutaneous lumbar foraminoplasty (PLF) and changed the site for foraminoplasty from tip of the SAP in Tessys technique to the base of the ventral SAP in our modified PLF. From April of 2007 to April of 2009, 148 patients with uncontained lumbar disc herniation were treated with modified PLF under fluoroscopic guidance with a specially designed instrument and PELD. Instrument design, technique note, and outcome of 5 years follow-up are included in this report.

## Methods

### Participants

From April of 2007 to April of 2009, 148 patients who met the inclusion criteria were treated with modified PLF-PELD.

Inclusion criteria: 1) Clinical signs of lumbar monoradiculopathy, dysesthesia, and decreased motor function recurrence after open discectomy were not excluded; 2) Concordant imaging evidence of monosegmental uncontained HDs with or without lateral recess stenosis at the same level demonstrated on preoperative magnetic resonance images (MRI) and/or computed tomography (CT) scans; migrated HDs should not exceed beyond the low rims of the adjacent pedicles; 3) Unsuccessful non-operative treatment including physical therapy and transforaminal epidural steroid injections for at least 12 weeks; 4) Patients who were able to provide voluntary, written informed consent to participate in this evaluation and willing to return for follow-ups.

Exclusion criteria: 1) Segmental instability on preoperative extension flexion radiographs; 2) Severe central stenosis on preoperative MRI or CT; 3) Cauda equina syndrome; 4) Very highly migrated HDs beyond the low rims of the adjacent pedicles; 5) Highly migrated L5-S1 HDs with an iliac crest higher than L4-5 disc level; 6) Patients unable to be positioned in a prone position; 7) Patients with histories of adverse reactions to local anesthetic; 8) Patients unwilling or unable to write consent to the operation; 9) Patients with systematic infection, bleeding diathesis, or on anticoagulants with a high risk of bleeding; 10) Patients using pacemaker equipment; 11) Patients with unrealistic expectations and uncooperative patients.

### Interventions

Approval to conduct the study was granted by the ethics committees of the first affiliated hospital of Chinese PLA's General Hospital. Institutional Review Board approved informed consent and protocols were provided to all the patients, which described details of the surgery including the mechanism of treatment, predictive outcome, potential risks, and side effects.

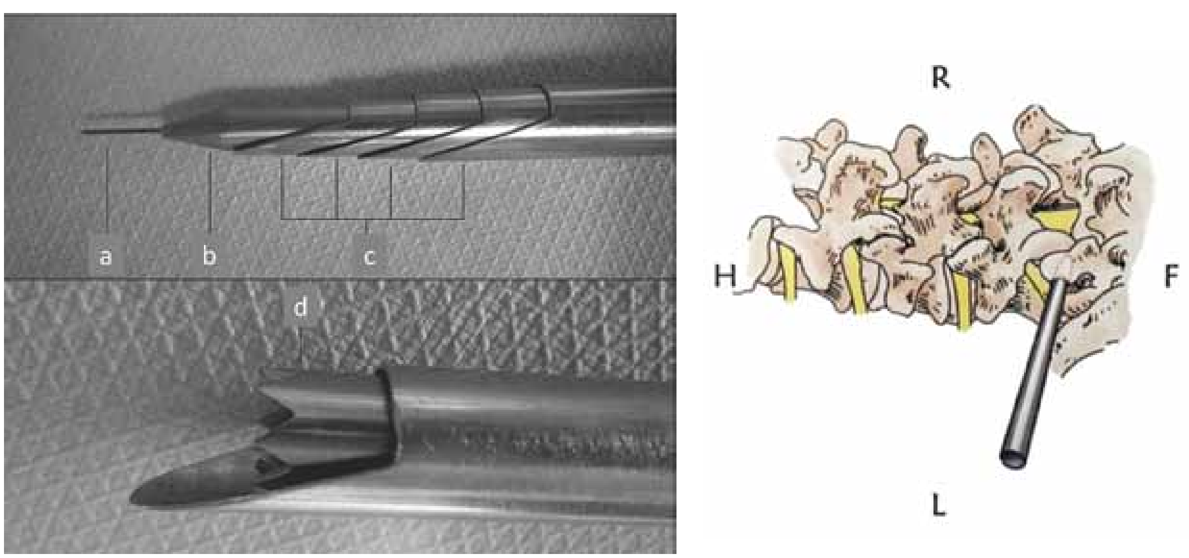



Fig. 1. *Composition of the instrument for modified PLF and its position. A: specially designed instrument consists of a guidewire (a), an obturator (b), a sequential graded duck-mouth protective cannula (c), and graded trephines (d). B: The bevel part of the protective cannula goes through the lower half of the intervertebral foramen. R-right; L-left; H-head; F-foot.*

## Surgical Tools

We used a patented specially designed instrument for PLF consisting of a guidewire with a 1 mm diameter, an obturator with a 7 mm diameter, 4 graded duck-mouth protective cannulas (inner-outer diameter: 7 – 8 mm, 8 – 9 mm, 9 – 10 mm, and 10 – 11 mm), and graded trephines (inner-outer diameter: 6 – 8 mm and 8 – 10 mm) (Fig. 1A). The distal end of duck-mouth-like cannulas is 2 cm in length. Half of it is flat; the other half has a bevel design. The bevel part is thin, so that it can go through the lower half of the intervertebral foramen between the SAP and posterior wall of the distal vertebra. The tip of the cannulas will be fixed on the posterior aspect of the superior endplate of the distal vertebrate, preventing the cannulas from moving (Fig. 1B). The trephine works inside the cannulas avoiding any damage to exiting and transversing nerve roots.

A Vertebris Spine Endoscope System (Richard Wolf GmbH, Germany) and tip-flexible electrode bipolar radiofrequency system (Elliquence LLC, USA) were used in PELD.

## Surgical Procedures

In all of the patients, the modified PLF-PELD procedure was performed under local anesthesia in the prone position on a radiolucent table using C-arm fluoroscopy. The patients communicated with the surgeon during the entire procedure. The skin entry point was usually about 9 to 15 cm from the midline. The point depends on the patient's body size, location of the HD, and foraminal dimension. To determine an appropriate entry point and approach angle, preoperative axial MRI or CT images should be used to calculate the distance of skin entry point of needle from the midline (Fig. 2). The entry point was determined at the intersection of the skin and horizontal line from the posterior aspect of the spinal process and the needle trajectory could be planed on preoperative MRI/CT to target the intervertebral foramen while avoiding the contents of the peritoneal sac.

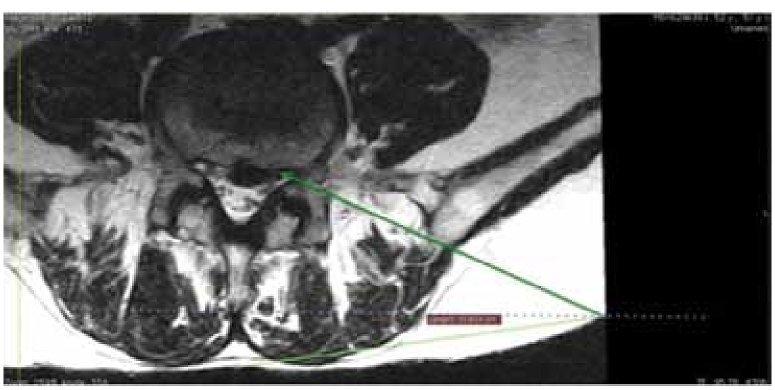


Fig. 2. *Preoperative planning of the entry point and needle trajectory: entry point was determined at the intersection of the skin and a horizontal line from the posterior aspect of the spinal process (dotted line), the distance of the skin entry point of the needle from the midline was calculated.*

After infiltrating the intended needle entry tract with 8 mL to10 mL of 0.5% lidocaine, a 15-gauge needle was inserted by the posterolateral approach. In the lateral view, the needle tip should lie at the posterior rim of the upper endplate of the distal vertebrate while the tip of the needle in the AP view should be at the medial pedicle line. The inclination of the needle trajectory depended on whether it is a down-migrated (Fig. 3A, 3B) or up-migrated disc (Fig. 4A, 4B). In case of a down-migrated herniation, the skin entry point of the needle started slightly above the level of the disc with the needle tip directed downwards making an angle of 20° – 30° with the upper endplate of the distal vertebrate. For an up-migrated disc, the skin entry point was placed along the level of the disc.

After infiltrating 15 – 20 mL of 0.5% lidocaine in the intervertebral foramen, the needle was replaced with a 1 mm guidewire. A blunt tapered cannulated obturator was passed over the guidewire under fluoroscopic monitoring until its tip reached the posterior rim of the upper endplate of the distal vertebrate in the lateral view. The first protective cannulas were passed over the obturator and advanced with twisting motions to the intervertebral foramen. After removal of the obturator, the first protective cannula was further rotated and advanced through the lower half of the intervertebral foramen between the SAP and posterior rim of the upper endplate of the distal vertebrate. The tip of the cannulas would be fixed on the posterior rim of the upper endplate of the distal vertebrate in the lateral view while positioned at the medial pedicle line in the AP view (Fig. 3C, 3D), preventing the cannulas from moving. The bevel part was

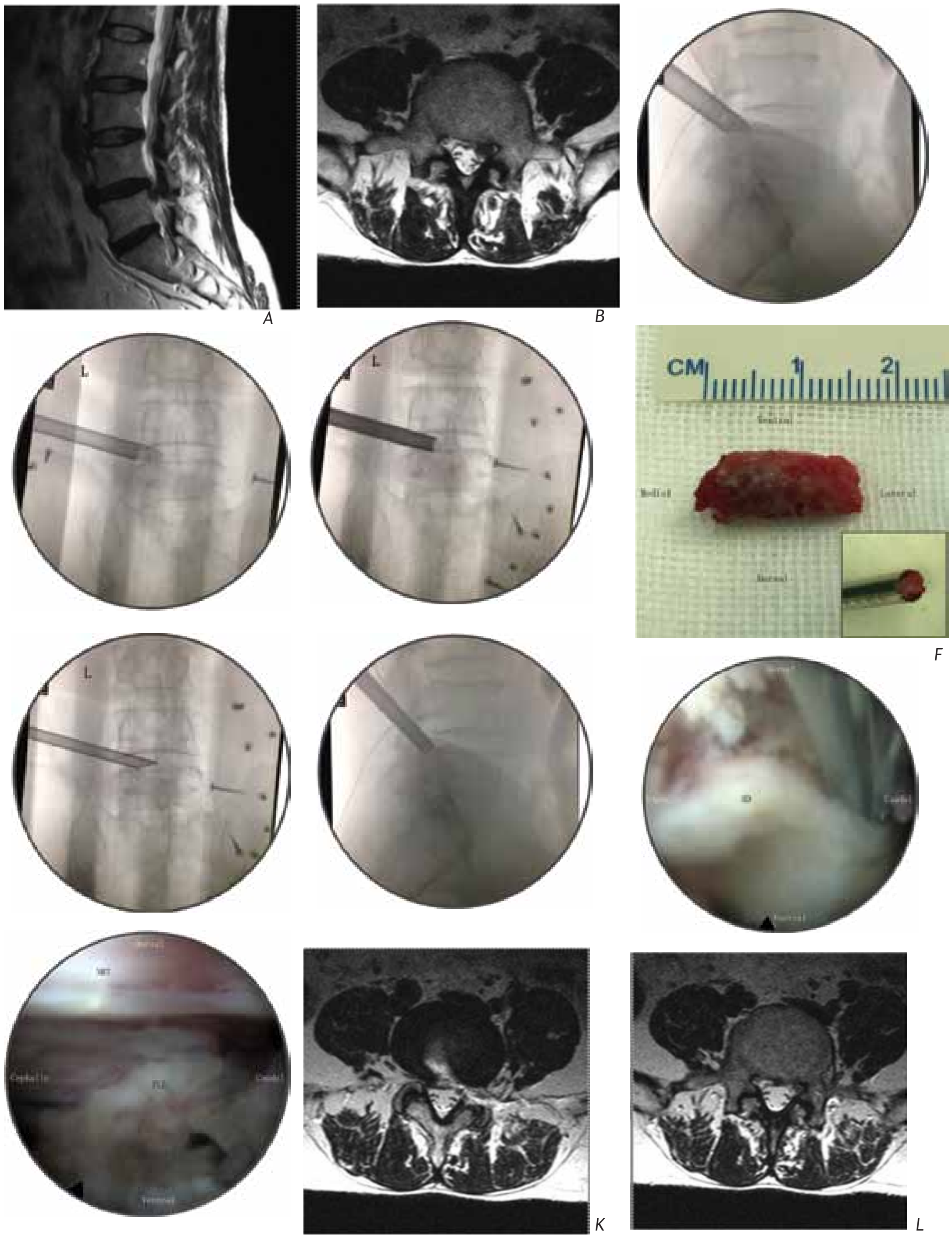
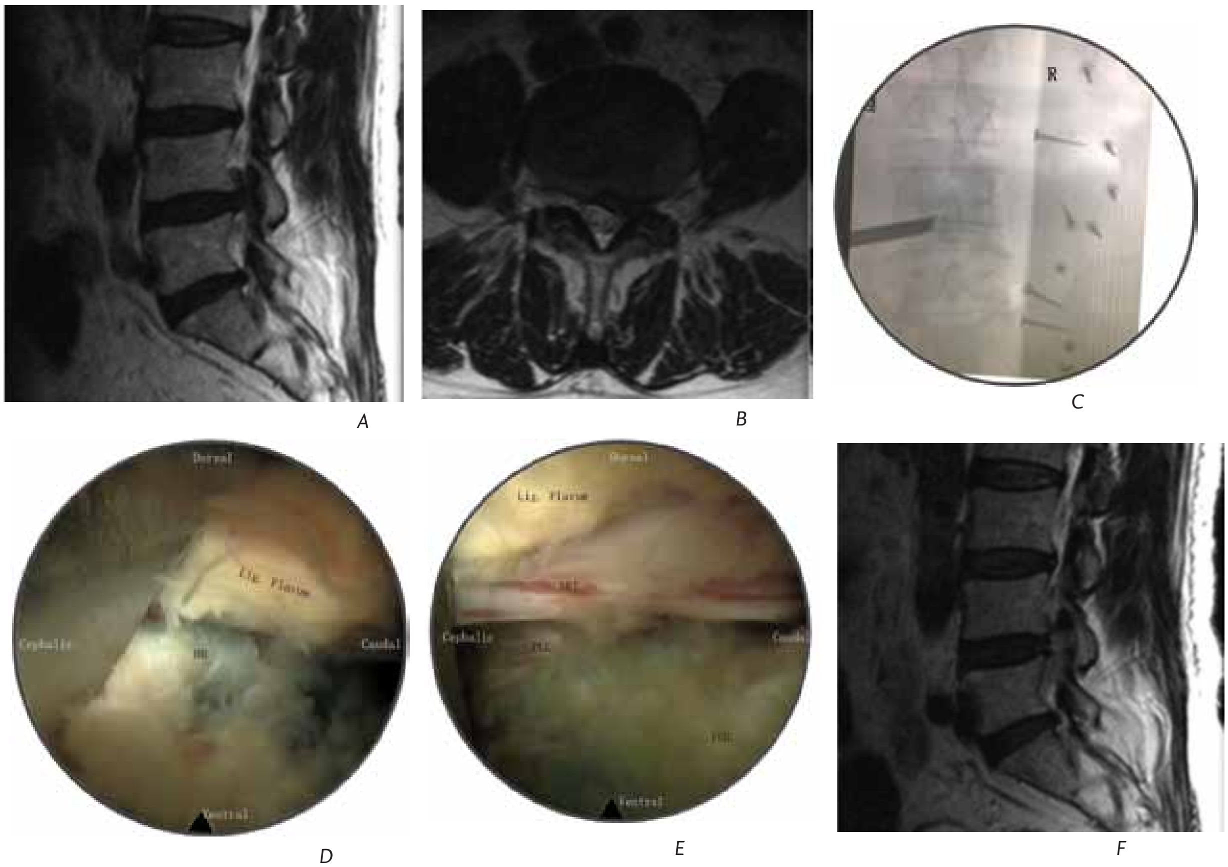



Fig. 3. *Downward migrated HD. A: Preoperative sagittal T2-weight MRI shows the downward migrated HD of L4-5. B: Preoperative axial T2-weight MRI shows the axilla HD. C: The tip of the protective cannulas should be fixed on the posterior rim of the upper endplate of the distal vertebrate in the lateral fluoroscopic view. D: The tip of the protective cannulas should be positioned at the medial pedicle line in the AP fluoroscopic view. E: Trephine should be advanced with careful rotation under fluoroscopic guidance. F: The ventral portion of the SAP could be taken out along with the trephine once the SAP was cut off. G: Position of the working cannula in the AP fluoroscopic view. H: Position of the working cannula in the lateral fluoroscopic view. I: Endoscopic dissection and resection of HD. J: Exploration of the transversing nerve root after decompression. K: Postoperative axial T2-weighted MRI shows the enlarged intervertebral foramen and decompression at the L4-5 disc level. L: Postoperative axial T2-weighted MRI shows the complete removal of the downward migrated HD. HD-herniated disc; NRT-nerve root; PLL-posterior longitudinal ligament.*



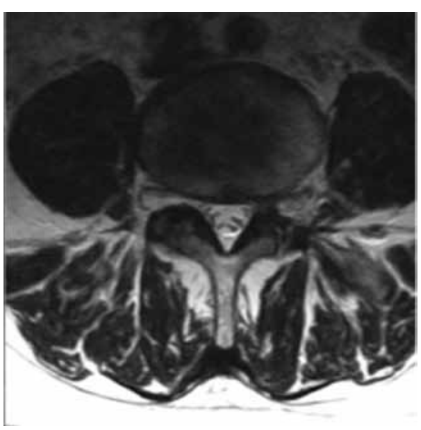
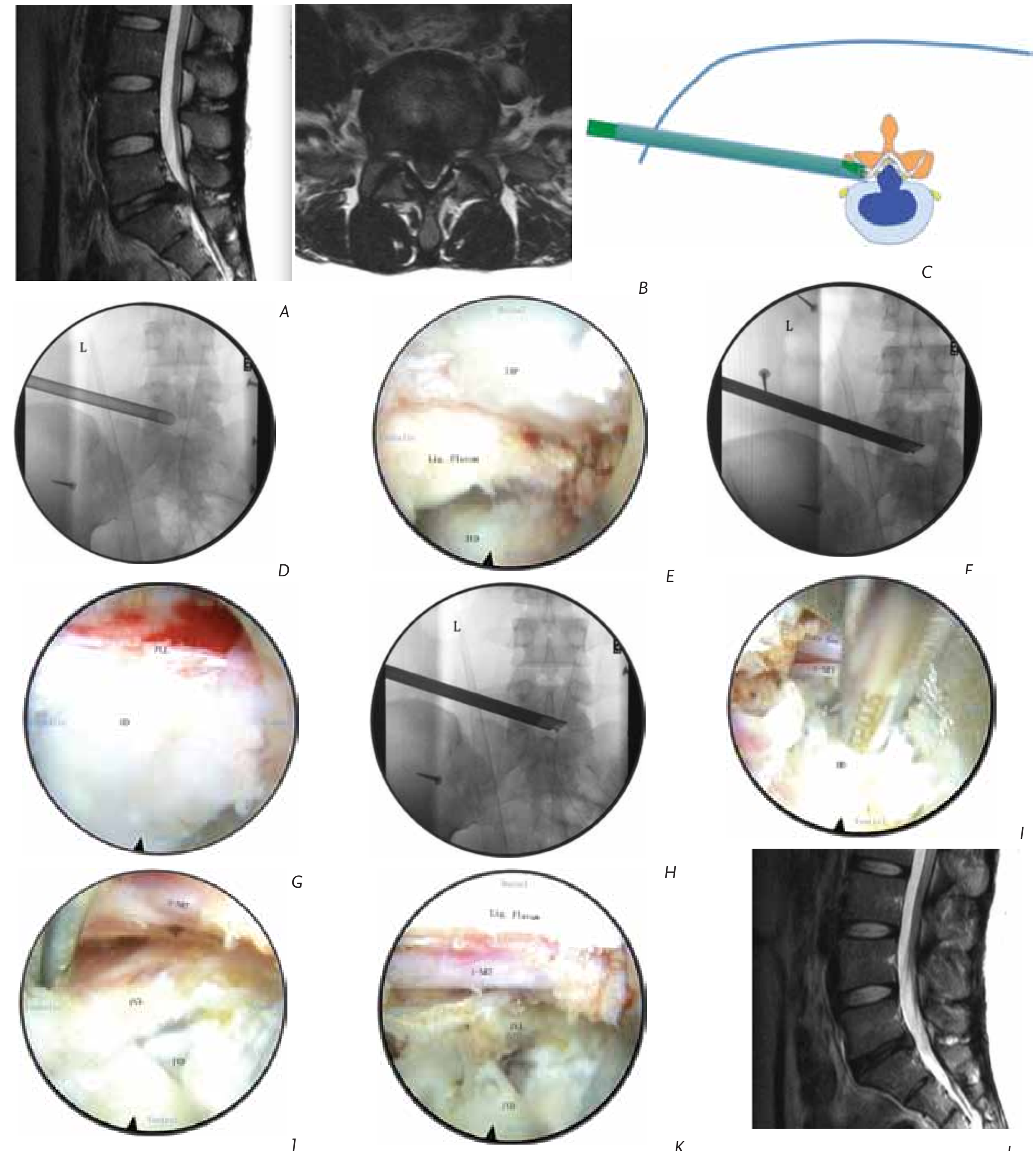




Fig. 4. *Upward migrated HD. A: Preoperative sagittal T2-weightrd MRI shows the upward migrated HD of L4-5. B: Preoperative axial T2-weighted MRI shows HD. C: Working cannula was adjusted upward to the HD in the AP fluoroscopic view. D: Endoscopic exposure of the HD. E: Exploration of the transversing nerve root after decompression. F: Postoperative sagittal T2-weighted MRI shows the complete removal of the upward migrated HD. G: Postoperative axial T2-weighted MRI shows the complete removal of the upward migrated HD. HD-herniated disc; NRT-nerve root; PLL-posterior longitudinal ligament; IVD-intervertebral disc; Lig. Flavum-flavum ligament.*

thin, so it could go through the lower half of the intervertebral foramen between the SAP and posterior wall of the distal vertebra. The bevel half of the cannulas' distal end faced dorsally and the flat half was pressed-fit on the lateral aspect of the SAP. Sequential protective cannulas were introduced over the smaller one. For low-grade migrated HDs located at the symptomatic side, the second protective cannula was enough; but the fourth protective cannula was needed for high-grade migrated HDs, high-grade canal compromise HDs, contralateral HDs, and HDs combined lateral recess stenosis.

Graded trephines were selected to perform the foraminoplasty: the first trephine for the second protective



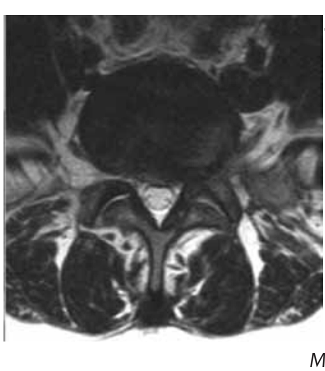




Fig. 5. *Centrally located high-canal compromised HDs. A: Preoperative sagittal T2-weighted MRI shows the centrally located high-canal compromised and low-grade downward migrated HD of L5S1. B: Preoperative axial T2-weighted MRI shows the centrally located high-canal compromised HD. C: Schematic diagram of the modified PLF with the specially designed instrument; the exiting nerve root was kept outside of the protective cannula and the transversing nerve root was protected by the ligament flavum; D: Primary position of the working cannula; E: Endoscopic view of the enlarged foramen; F: The working cannula was advanced into the epidural space anterior to thedural sac. G: Exposure of the HD under endoscopic visualization. H: The working cannula was advanced into the contralateral epidural space anterior to the dural sac. I: Exploration of the contralateral nerve root. J: A radiofrequency-thermal annuloplasty was performed. K: Exploration of the ipsilateral transversing nerve root after decompression. L: Three months postoperative sagittal T2-weighted MRI shows the healed disc with flattened posterior annulous fibrosis. M: Three months postoperative axial T2-weighted MRI shows the healed disc with flattened posterior annulous fibrosis. IAP-inferior articular process; SAP-superior articular process; HD-herniated disc; c-NRT-contralateral nerve root; i-NRT-ipsilateral nerve root; PLL-posterior longitudinal ligament; IVD-intervertebral disc; Lig. Flavum-flavum ligament.*

cannula and the second trephine for the fourth protective cannula. With the tip of the protective cannula anchored in the foramen and treated as a fulcrum, the trajectory inclination of the foraminoplasty could be adjusted utilizing the mobility of the back muscle. In case of a down-migrated herniation, the trephine was directed downwards making an angle of 20° – 30° with the upper endplate of the distal vertebrate (Fig. 3E). For an up-migrated disc, the trephine was directed upwards making an angle of 20° – 30° with the lower endplate of the proximal vertebrate. For low-grade migrated HDs located at the symptomatic side, the trephine was advanced anteromedially making an angle of 20° – 30° with the coronal plane; but for high-grade migrated HDs, high-grade canal compromise HDs (Fig. 5A, 5B), contralateral HDs, and HDs combined lateral recess stenosis (Fig. 6A), the trephine should be advanced nearly horizontally. The trephine should be advanced with careful rotation under fluoroscopic guidance. The ventral portion of the SAP could be taken out along with the trephine once the SAP was cut off (Fig. 3F). During this manipulation, the exiting nerve root was kept outside of the protective cannula and the transversing nerve root was protected by the ligament flavum (Fig. 5C, 5E). The patient was conscious and was asked throughout the procedure if he or she was experiencing leg pain, characteristic of manipulation of the nerve root, so nerve root damage could be avoided.

The obturator was inserted into the enlarged foramen and the protective cannula was replaced with an 8 mm working cannula (Figs. 3G, 3H, 5D). A 25° endoscope with a working channel of 4.1 mm and length of 205 mm was introduced.

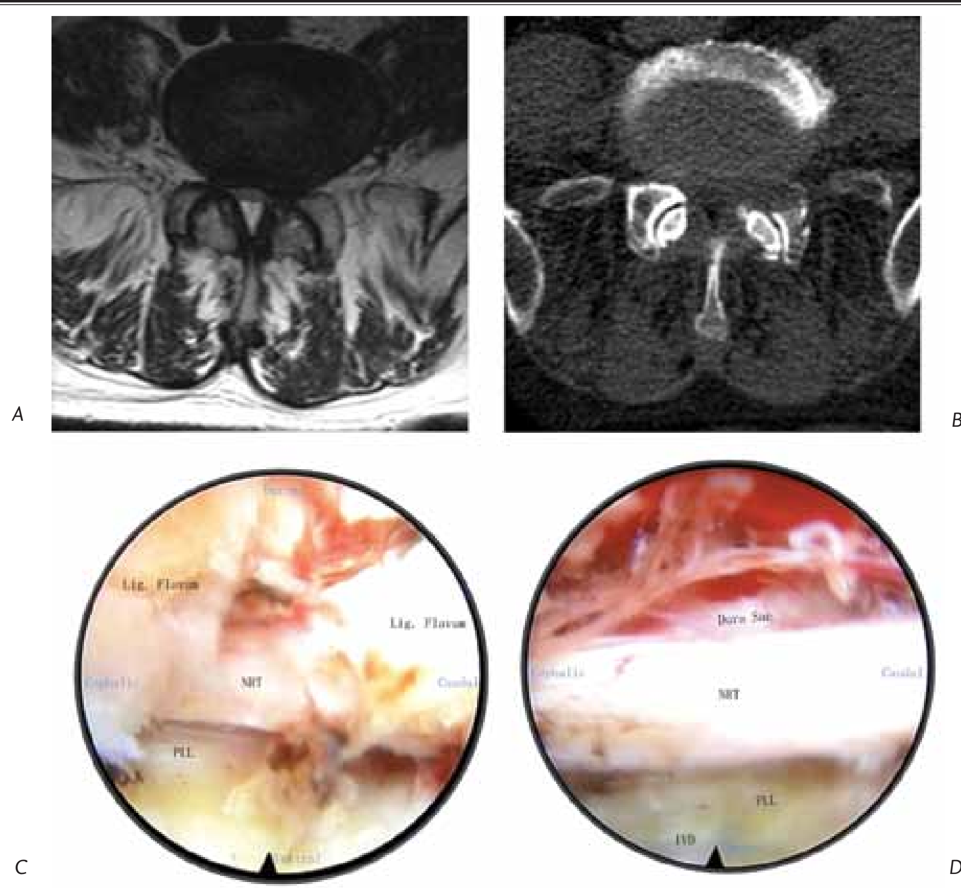



Fig. 6. *Decompression of the lateral recess stenosis. A: Preoperative axial T2-weighted MRI shows the left lateral recess stenosis at the L4-5 disc level. B: Postoperative axial CT scan shows adequate decompression of the left lateral recess at the L4-5 disc level. C: Endoscopic view of the hypertrophied flavum ligament and compressed transversing nerve root. D: Exploration of the transversing nerve root after lateral recess decompression. NRT-nerve root; PLL-posterior longitudinal ligament; Lig. Flavum-flavum ligament; IVD-intervertebral disc.*

In HDs combined with lateral recess stenosis, the hypertrophied ligament flavum lateral and posterior to the transversing nerve root should be resected to achieve lateral recess decompression (Fig. 6B, 6C). In other situations, the ligament flavum should be preserved to decrease postoperative epidural scar formation (Figs. 4E, 5E, 5K). The working cannula was advanced into the epidural space anterior to the dural sac under endoscopic visualization (Fig. 5F, 5G). Bleeding was controlled with the help of a flexible bipolar radiofrequency probe. The tip of the probe, being curved, was used to palpate for annular rupture. After intradiscal decompression was performed, the working cannula was adjusted to find and completely remove the migrated or sequestered discs (Fig. 3I). Since the intervertebral foramen was adequately enlarged, additional maneuvers like levering the cannula to make it more horizontal, downward or upward tilting (Fig. 4C, 4D), or even contralateral (Fig. 5H, 5I) could be easily achieved so that direct visualization and excision of the fragments could be finished. After excision of the ruptured fragment, the traversing nerve root with posterior longitudinal ligament could be easily seen (Figs. 3J, 4E, 5J, 5K, 6D). Pressure was controlled by intermittently blocking the irrigation fluid outflow with the thumb, allowed the traversing nerve root to move freely which confirms complete decompression. A radiofrequency-thermal annuloplasty was typically performed at the end of the discectomy (Fig. 5J). After adequate hemostasis with a bipolar coagulator, the endoscope was withdrawn, and a sterile dressing was applied with a one-point subcutaneous suture.

All the patients underwent postoperative MRI/CT one day after surgery (Figs. 3K, 3L, 4F, 4G, 5L, 5M, 6B) and were discharged.

### Postoperative Management

The patient was fitted with a lumbar back brace and transferred to the ward. No medicinal thrombosis prophylaxis was provided. Follow-up examination and MRI checkup was performed the next morning. Physiotherapy and back exercise began after one week. The lumbar back brace was worn for approximately 4 – 6 weeks to limit the range of lumbar motion, especially lumbar flexion and rotation, so that the ruptured annular fibrosis could achieve favorable healing in the rehabilitation period and recurrence of disc herniation could be decreased.

### Outcome Assessment

Outcomes of symptoms were evaluated by follow-up interviews at 3 months, 6 months, one year, and 5 years after surgery. Low back pain and leg pain were measured by visual analog scale (VAS) score (1 – 100). Functional outcomes were assessed by using Oswestry Disability Index (ODI) (21) and modified MacNab criteria (22,23). For MacNab criteria at year 5 after surgery, "excellent" was given to patients who were free of pain and deficit, without restriction of mobility; "good" was given to patients with residual symptoms or deficits not impeding a normal life; "fair" was given to patients with some improvement of functionality but who remained handicapped; and "poor" was given to patients with no improvement at all.

The comparisons of improvement (percentage of pain relief) for low back pain to leg pain were performed. Correlation between duration of the preoperative symptoms and the percentage of postoperative pain relief was also evaluated.

Percentage of pain relief (%) was calculated as (VAS score before operation - VAS score after operation) ×100/ VAS score before operation.

### Statistical Analysis

Statistical analyses were performed with SPSS 11.5 software (SPSS Inc., Chicago, IL). Pre-operative and post-operative (3 month, 6 months, one year, and 5 years) VAS scores of low back pain and leg pain, as well as ODI values were analyzed with ANOVA. Preoperative and postoperative related nerve root function status was analyzed with Chi-square test. The comparisons of improvement (percentage of pain relief) for low back pain to leg pain were analyzed with t-test. Correlation between duration of the preoperative symptoms and the percentage of postoperative pain relief were analyzed with Pearson test. $P < 0.01$ was considered as significant.

## Results

### Patient's Demographic Characteristics

Using a specially designed instrument for modified PLF-PELD, 148 patients with disc herniation were surgically treated, 134 cases were followed up. Reasons for loss to follow-up include loss of contact in 11 patients and death from other diseases in 3 patients. Follow-up data were obtained from 134 patients out of 148, including 14 cases at L3-4, 78 cases at L4-5, and 42 cases at L5-S1. Patients ranged in age from 18 to 78 years (mean age, 41.4 years), including 68 men and 66 women. One hundred-eight cases were prolapse type, while 26 cases

Table 1. *Changes of preoperative and postoperative ODI, VAS scores and percentage of pain relief of low back pain and sciatica ($\bar{x}$ ±s).*

| Time point | Pre-operation | 3 months post-operation | 6 months post-operation | 1 year post-operation | 5 years post-operation | F values |
|---|---|---|---|---|---|---|
| VAS of low back pain | 26.05±11.89 | 7.44±6.65# | 5.74±5.83# | 5.04±7.09# | 5.12±7.19# | 165.85* |
| Percentage of pain relief of low back pain | | 71.98±23.76 | 78.30±19.78 | 80.03±30.63 | 80.03±27.82 | |
| VAS of sciatica | 75.89±9.65 | 3.10±5.84# | 1.47±3.56# | 1.16±3.22# | 0.93±3.17# | 4436.94* |
| Percentage of pain relief of sciatica | | 95.85±8.04@ | 97.93±5.04@ | 98.46±4.31@ | 98.75±4.33@ | |
| ODI | 75.27±9.71 | 28.51±5.65# | 20.42±5.65# | 14.62±5.51# | 13.83±4.68# | 2025.00* |

* $P$ <0.01, ANOVA; #$P$ <0.01, compared to pre-operation, LSD; @ $P$ <0.01, compared to percentage of pain relief of low back pain, t-test

were sequestration type. Pre-operative symptoms and deficits included nerve root dermatome hypoesthesia in 98 patients (73%), nerve root myotome muscle weakness in 32 patients (23%), and weakening or disappearance of tendon reflex in 43 patients (32%).

### Postoperative Outcomes

No case required conversion to an open procedure during the surgery. No patient needed a blood transfusion. No patients had infections. Operative time ranged from 40 to 80 minutes (average, 65 minutes). Low back pain and leg pain were significantly relieved immediately after surgery in all patients. Five patients experienced dysesthesia in the exiting nerve all at the L5-S1 level. Complaints were reduced after one week's treatment with medium frequency pulse electrotherapy. MRI examination showed adequate removal of the herniated disc in all patients. Five cases required a revision surgery (3.7%) after recurrence, thus being excluded from the patient list of quantitative indices follow-up. The rest of the 129 cases were analyzed with complete follow-up data. Preoperative and postoperative VAS scores and percentage of relief of low back pain and leg pain, as well as ODI are summarized in Table 1. As the data show, VAS scores and ODI values were significantly lower at all time-points after surgery. The percentage of relief in leg pain was significantly higher than that of low back pain at all time-points after surgery. Average duration of preoperative leg pain in all 129 cases was 5.0 (3 – 36) months while that of preoperative combined low back pain in 116 cases was 35.1 (1 – 240) months. There was no significant correlation between duration of the preoperative symptoms and the percentage of postoperative pain relief. MacNab scores at 5 years after surgery were obtained from 134 patients. Seventy-five cases were rated "excellent" and 49 were rated "good." Five patients experienced heavier low back pain, and thus were classified as "fair." Five cases with recurrence were rated "poor." Preoperative and postoperative (5 years follow-up) related nerve root function status is summarized in Table 2. Sensation and muscle strength recovered significantly ($P < 0.01$), while tendon reflex was not changed ($P = 0.782$).

## Discussion

### Safety of a Specially Designed Instrument for Modified PLF

Endoscopic foraminoplasty with a side-firing laser, high-speed burr, trephine, or reamer, etc. has been proven to be a safe procedure to widen the lumbar foramen by removing part of bone and ligamentous tissue surrounding the foramen (17,24-28). However, the disadvantages of endoscopic foraminoplasty are quite obvious, for example, expensive equipment, low working efficiency, inadequate decompression for lateral recess stenosis, and risk of heat-damage to surrounding spinal nerves (11,12,15,16). Hoogland et al (19,29,30) invented the Tessys technique which uses a graded trephine to widen the foramen gradually. But in such surgery, the trephine blade makes contact with para-foramen soft tissue, the dura sac, and nerve roots, causing concerns about damage to nerves (30). Based on Hoogland's method, we invented a specially designed instrument for modified PLF with graded duck-mouth-like protective cannulas which are placed to the ventral side of the SAP, excluding the exiting nerve root from the working zone of the trephine. Driven by hand, the trephine could only cut off the bony structure of the SAP, not the ligament. So, the flavum ligament and joint capsule remained between the blade of the trephine and the transversing nerve root, avoiding any damage to the nerve root or cauda equina nerve tissue inside the

Table 2. *Comparison of preoperative and postoperative function of related nerve roots.*

| Function of Nerve roots | Condition | Pre-operation | 5 years post-operation | *P* values* |
|---|---|---|---|---|
| Sensation | Normal<br>Decreased | 39<br>90 | 115<br>14 | 0.000 |
| Muscle strength | Normal<br>Decreased | 104<br>25 | 127<br>2 | 0.000 |
| Reflex | Normal<br>Decreased | 91<br>38 | 94<br>35 | 0.782 |

*Chi-square test

dural sac. Patients were kept awake under local anesthesia making it possible for surgeons to get instant feedback from patients. The sino-vertebral nerve surrounding the foramen was anesthetized with 0.5% lidocaine solution, reducing pain without affecting the function of the nerve roots. This is important to ensure the safety of modified PLF.

Although 5 patients (3.7%) experienced dysesthesia at the L5-S1 level, symptoms were significantly relieved in a week after treatment with medium frequency pulse electrotherapy. Even so, it was much lower than that reported by Knight et al (17) and Ahn et al (18). Knight et al (17) reported 19% transient postoperative “flares” when a side-fire laser was used; while Ahn et al (18) reported 6.1% postoperative dysesthesia after endoscopic foraminotomy with an endoscopic high-speed drill. These short-lived symptoms are most likely due to irritation of the nerve. Retrieval of highly migrated herniation at the L5-S1 level is much more difficult when compared with other levels. A high level of the iliac crest, thick transverse process, and marginal osteophytes hinder an easy passage of the working sheath of the endoscope. Exiting nerve roots could be irritated during PLF-PELD. In these cases, an interlaminar approach proves to be a better approach in terms of simplicity and effectiveness (31). Possible ways to limit dysesthesia encountered with L5-S1 level intervention include 1) excluding the patients with L5-S1 disc herniation with a high iliac crest; 2) introducing the smallest protective cannula first and applying the smallest trephine for smaller foraminoplasty so that enough space was made for the larger protective cannula and larger foraminoplasty gradually; and 3) converting to percutaneous endoscopic lumbar discectomy through an interlaminar approach in which the ligament of the flavum is split posteriorly so that the endoscope can be introduced into the epidural space and the targeted discectomy can be performed without any violation to the exiting nerve root.

### HDs Suitable for Treatment with Modified PLF

For simple uncontained lumbar disc herniation, the first trephine (inner-outer diameter: 6 – 8 mm) was big enough to create a working zone to resect the herniated tissue. There was no need to decompress the foramen and lateral recess. Using the first trephine with an 8 mm outer diameter, we could limit the cut to no bigger than 4 mm and make a curved surface on the ventral SAP due to the protection of the duck-mouth-like cannulas. Such a cut caused no damage to the articular surface and joint capsule of facet joints and no harm to the stability of the lumbar segment. And such a cut ensured the foramen was wide enough to let the cannulas go into the spinal canal, creating a working zone for most cases of discectomy.

For HDs combined with lateral recess stenosis, intervertebral foramen stenosis, and complex HDs with high-grade migration or high-grade canal compromise, the secondary trephine (inner-outer diameter: 8 – 10 mm) was needed to decompress the foramen and lateral recess. Using the secondary trephine, we could widen the foramen and lateral recess to 10 mm in height. The undercut of the SAP could be limited to 5 mm due to the protection of the duck-mouth-like cannulas. The upper part of the SAP and part of the ventral SAP of the facet joint could be cut, thus decompressing the foramen and lateral recess effectively. The intervertebral foramen was enlarged wide enough for maneuvers of the working cannula like levering the cannula to make it more horizontal, downward or upward tilting, or contralateral. So high-grade migrated HDs, high-grade canal compromised HDs, and even contralateral HDs could be easily reached so that direct visualization and excision of the fragments could be finished. In this study of modified PLF-PELD using a specially designed instrument, 148 patients with disc herniation were successfully surgically treated without any technique failure or any patient requiring conversion to an open procedure during the surgery, and postoperative MRI examination showed adequate removal of HD in all patients.

### Influence of Modified PLF with Specially Designed Instrument to the Stability of the Lumbar Segment

Osman et al (32) studied the pathoanatomy, intervertebral foraminal area, and flexibility changes after posterior and transforaminal decompression in 10 fresh, cadaveric, 2-vertebrae, functional spinal units to determine the feasibility of an endoscopic transforaminal approach as an alternative to conventional approaches, to establish the adequacy of transforaminal decompression without destabilizing the spine, and to study the structural changes in the spine after decompression. After transforaminal decompression, the anteromedial third of the superior facet, the anterior part of inferior facet, and the portion of the joint between them were removed. The arthroscope inserted through the decompressed foramen could visualize easily the anterior surface of the laminae and the intervening ligament flavum. The arthroscope could be passed anterior to the dura to visualize the entire width of the posterior aspect of the intervertebral disc (32). Transforaminal decompression provides direct access to the lateral foraminal canal and direct visualization of the superior facet – the main culprit in lateral canal and foraminal stenosis. Additionally, the transforaminal approach provides easy access to the whole extent of the bulging or osteophytic disc, the inferior facet, and the front of the laminae. The only ligamentous structure affected by the transforaminal approach is the anterior facet joint capsule and the lateral part of the ligament flavum. A 45.5% increase in the intervertebral foraminal area was possible, there was no flexibility change, and minimal anatomic damage to the spine was noted after transforaminal decompression.

But only a limited amount of the posterolateral disc is accessible through the posterior approach and more facet excision would be necessary to access the lateral reaches of the foraminal canal. Excessive removal of the facet joints has been associated with destabilization of the spine (33,34). A 34.2% increase in the intervertebral foraminal area and a significant increase in extension and axial rotation flexibility were noted after the posterior decompression.

So transforaminal decompression produced a significantly larger increase in the intervertebral foraminal area than posterior decompression, without increasing the range of motion or neutral zone in any direction.

The surgical technique used in this study is just like that used by Osman et al (32). Because there was no violation of the anatomic integrity of the spine in the transforaminal approach, the risk of surgically induced instability was minimized.

### Outcomes of Modified PLF-PELD

Nellensteijn et al (35) reported in a systematic literature review that current evidence is not enough to support a better efficacy of transforaminal endoscopic surgery over open microdiscectomy in patients with symptomatic lumbar disc herniation or vice versa. To form a solid conclusion on this topic, high-quality randomized controlled trials with sufficient sample sizes are required to compare the effectiveness of transforaminal endoscopic surgery and open microdiscectomy.

Kambin et al (2) reported an 88.3% success rate in case series of 169 patients with lumbar disc herniation in 24-month follow-up. Meanwhile, open laminectomy and discectomy requires patients to use narcotics for a longer duration postoperatively than video-assisted arthroscopic microdiscectomy.

Reoperation rates of PELD have been reported from 2.3% to 15.7% (5,10,20,30,36-38). There is no significant difference in the reoperation rates between open discectomy (13.7%) and endoscopic discectomy (12.4%) (39). Choi et al (9) reviewed 10,228 patients who had undergone inside-outside PELD in 12 years; 436 (4.3%) cases were unsuccessful. The causes were incomplete removal of HDs in 283 patients (2.8%), recurrence in 78 (0.8%), persistent pain even after complete HD removal in 41 (0.4%), and approach-related pain in 21 (0.2%). Incomplete removal of the HD was caused by inappropriate positioning (95 cases; 33.6%) of the working channel and occurred in central HDs (91 cases; 32.2%), migrated HDs (70 cases; 24.7%), and axillary type HDs (63 cases; 22.3%). Lee et al (38) reported a 15% failure rate in central located high-canal compromised HDs and 15.7% failure rate in high-grade migration HDs.

PELD recurrence rates are reported to range from 0% to 7.4% (9,13,27,29,37,40-42). Recurrence rates after open discectomy have been reported to range from 1% to 21% (43,44). Several studies showed no difference in recurrence rates between PELD and open discectomy (7,39).

Surgically unappreciated disc fragment remnants and incomplete decompression by piecemeal removal may lead to a higher early recurrence. To reduce recurrence rates, complete removal of the herniated mass is required including the basal and extruded parts (45).

Application of foraminoplasty further improved the effectiveness of endoscopic discectomy in treating lumbar disc herniation. With endoscopic foraminoplasty and PELD, Lee et al (46) reported 88% (22/25) favorable outcomes in extruded disc herniation at the L5-S1 level. Choi et al (11) treated highly migrated intracanal lumbar disc herniation and 91.4% (53/59) of patients experienced a satisfactory outcome. Lewandrowski et al (12) reported 85% (186/220) excellent and good results in patients with lateral stenosis with and without herniated disc. Clinical failures occurred in patients with bony stenosis in the lateral recess and entry zone of the neuroforamen (11,12,27) because endoscopic foraminoplasty with tiny tools cannot adequately decompress the lateral recess with the restriction of the working channel of a rigid endoscope (11,12,15,16).

With Tessys technique, 83.9% – 95.3% excellent or good results according to MacNab's score were achieved in patients with a single level herniation (prolapsed or sequestered HDs, recurrent HDs) (19,27,30) and 69.7% in patients with multi-level pathologies receiving one procedure (27). The recurrence rate was 3.6% – 4.62% (19,30,47).

In the present study, we reported case series of 134 patients with uncontained lumbar disc herniation treated with modified PLF-PELD. The results of 92.5% of cases were "excellent" or "good" according to MacNab's score. Five cases (3.7%) had recurrent herniation at the same level. These results are better than previous studies with endoscopic foraminoplasty. One of the reasons might be that the specially designed instrument not only adequately widened the foramen and lateral recess simultaneously but also effectively protected the nerve roots.

We found that the percentage of postoperative relief in leg pain was significantly higher than that in low back pain and there was no significant correlation between duration of the preoperative symptoms and the percentage of postoperative pain relief. Leg pain was simply caused by disc herniation, but low back pain might arise from discogenic low back pain, facet syndrome, or soft tissue, etc. So low back pain couldn't be completely relieved by simple nerve root decompression.

## Conclusion

In conclusion, modified PLF-PELD with our specially designed instrument is a less invasive, effective, and safe surgery for complex uncontained lumbar DH.

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