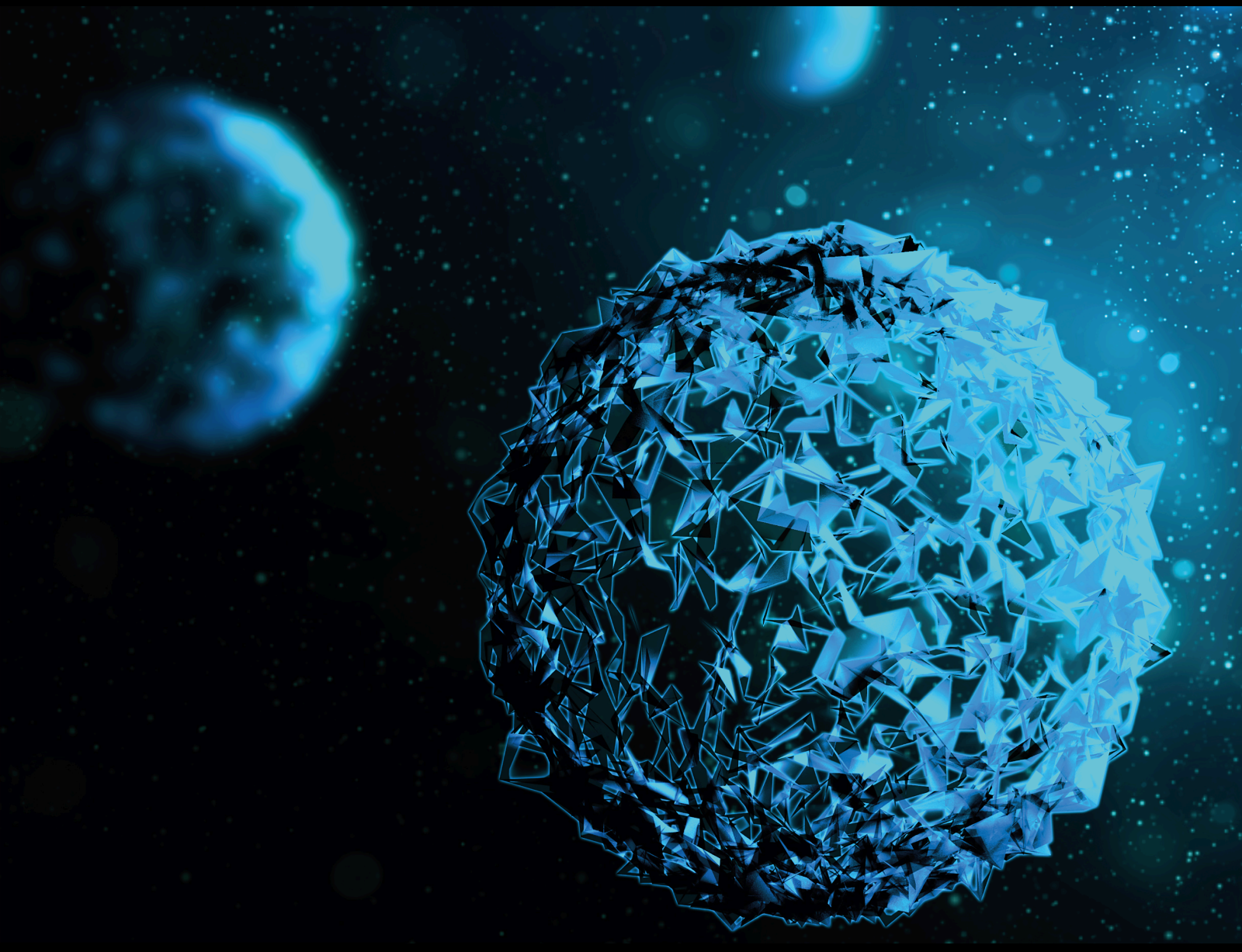
BioMed Research International

# Percutaneous Endoscopic Spine Surgery: New Horizons in the Management of Spinal Disorders

Lead Guest Editor: Hyeun S. Kim
Guest Editors: Michael Mayer, Yue Zhou, Akira Dezawa, and Arvind G. Kulkarni



# Percutaneous Endoscopic Spine Surgery: New Horizons in the Management of Spinal Disorders

BioMed Research International

# Percutaneous Endoscopic Spine Surgery: New Horizons in the Management of Spinal Disorders

Lead Guest Editor: Hyeun S. Kim
Guest Editors: Michael Mayer, Yue Zhou, Akira Dezawa, and Arvind G. Kulkarni

## Section Editors

Penny A. Asbell, USA
David Bernardo, Spain
Gerald Brandacher, USA
Kim Bridle, Australia
Laura Chronopoulou, Italy
Gerald A. Colvin, USA
Aaron S. Dumont, USA
Pierfrancesco Franco, Italy
Raj P. Kandpal, USA
Fabrizio Montecucco, Italy
Mangesh S. Pednekar, India
Letterio S. Politi, USA
Jinsong Ren, China
William B. Rodgers, USA
Harry W. Schroeder, USA
Andrea Scribante, Italy
Germán Vicente-Rodriguez, Spain
Momiao Xiong, USA
Hui Zhang, China

## Academic Editors

### Surgery

Ming Chen, Taiwan
Andrea Ferri, Italy
Georg Gradl, Germany
Christian R. Habermann, Germany
Ho-Seong Han, Republic of Korea
Shiro Imagama, Japan
Hiroki Ito, Japan
Jussuf Thomas Kaifi, USA
Kan Kajimoto, Japan
Kazutaka Kamiya, Japan
Hirotoshi Kobayashi, Japan
Achim Langenbucher, Germany
Myong Cheol Lim, Republic of Korea
Kosei Maemura, Japan
Takahisa Matsuda, Japan
Ken Ohnita, Japan
Giuseppe Piccinni, Italy
Claudia Maria Radu, Italy
Zbigniew Rybak, Poland
József Szalma, Hungary
Mariarita Tarallo, Italy

# Contents

**A Comparison of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Lumbar Disc Herniation in the Korean: A Meta-Analysis**

Manyoung Kim, Sol Lee, Hyeun-Sung Kim, Sangyoon Park, Sang-Yeup Shim, and Dong-Ju Lim

Review Article (8 pages), Article ID 9073460, Volume 2018 (2018)

Hindawi
BioMed Research International
Volume 2019, Article ID 6492675, 10 pages
https://doi.org/10.1155/2019/6492675

*Research Article*

# Predictive Scoring and Risk Factors of Early Recurrence after Percutaneous Endoscopic Lumbar Discectomy

**Hyeun Sung Kim**,[1] **Jong Duck You**,[2] **and Chang Il Ju**[2]

[1]*Department of Neurosurgery, Nanoori Hospital, Seoul, Republic of Korea*
[2]*Department of Neurosurgery, Chosun University Hospital, Gwangju, Republic of Korea*

Correspondence should be addressed to Chang Il Ju; jchangil@chosun.ac.kr

Received 12 September 2018; Accepted 30 July 2019; Published 7 November 2019

Academic Editor: Pasquale De Bonis



*Purpose.* To predict the early recurrence after full endoscopic lumbar discectomy, we analyzed factors related to demographic factor anatomical factors, operative method, and postoperative management, and predicted the possibility of recurrence according to the scoring system. *Materials and Methods.* In this prospective study, we enrolled 300 patients who underwent 1 out of 3 surgical procedures. The patients were randomized into one of the following groups: group A ($n = 100$), transforaminal inside-out approach; group B ($n = 100$), transforaminal outside-in approach; and group C ($n = 100$), interlaminar approach. The clinical results were evaluated by a visual analogue scale (VAS). Related factors evaluated with points of (A) demographic factors: (1) age, (2) gender, (3) BMI, (B) anatomical factors: (4) disc degeneration scale, (5) modic change, (6) number of involved disc herniation, (7) history of discectomy (first, recurred), (8) herniated disc level, (9) disc height, (10) segmental dynamic motion, (11) disc location, (C) operation factors: (12) annulus preservation along the disc protrusion, (13) approach method (transforaminal inside-out, transforaminal outside-in, interlaminar); (D) postoperative care factors: (14) early ambulation, (15) spinal orthosis (corset) application. Among these, we analyzed statistically significant recurrence risk factors after PELD in all patients and early recurrence predicting score ratio was obtained. *Results.* The overall recurrence rate was 9.33%. The recurrence rate was 11%, 10%, and 7% for groups A, B, and C, respectively. Average early recurrence time was 3.26 months. The change in preoperative and postoperative VAS score was from 8.07 to 1.39, 8.34 to 1.34, and 8.14 to 1.86 in groups A, B, and C, respectively. The recurrence rate based on the (1) age was <40 years: 5.22% (6/115), 41–60 years: 16.1% (20/124), and >61 years: 3.07% (2/65); (2) gender was male: 13/139 (9.35%), female: 15/161 (9.32%); (3) BMI was obese: 17.57% (13/74), overweight: 11.6% (9/77), underweight: 6.35% (4/63), and normal weight: 2.33% (2/86); (4) degeneration scale was grades 1–2: 2% (1/50), grade 3: 7.4% (10/135), and grades 4–5: 14.8% (17/115); (5) modic change was type I: 25% (3/12), type II: 14.3% (1/7), type III: 33% (1/3), and no modic change: 8.27% (23/278); (6) number of involved disc herniation was 1 level: 3.9% (5/128), 2 level: 10.4% (13/125), 3 levels: 18.9% (7/37), and 4 levels: 30% (3/10); (7) history of discectomy was first: 8.83% (25/283) and repeated: 17.65% (3/17); (8) herniated disc level was L1–L2/L2–L3/L3–L4: 3.95% (3/76) and L4–L5: 14.6% (18/123); (9) disc height was <80%: 17.14% (6/35), 81%–100%: 8.16% (12/147), and >101%: 8.5% (10/118); (10) segmental dynamic motion was 1–10°: 8.58% (20/233) and 11–20°: 11.9% (8/67); (11) disc location was central: 7.41% (2/27), foraminal: 3.03% (2/66), and inferior/superior/paracentral: 11.59% (24/207); (12) radical annulotomy was 8.05% (7/87) vs. 9.86% (21/213); (13) approach method was transforaminal (inside-out): 11% (11/100), transforaminal (outside-in): 10% (10/100), and interlaminar: 7% (7/100); (14) early ambulation was 16.42% (23/140) vs. 3.13% (5/160); and (15) spinal orthosis application was 7.35% (10/136) vs. 10.98% (18/164). According to the above results, after summation of all scores, the early recurrence predicting score: recurrence rate ratio was 1–4: 0% (0/23), 5–8: 7.1% (13/183), 9–12: 8% (6/75) and 13–16: 100% (10/10). *Conclusions.* Early recurrence after PELD is associated with several risk factors such as BMI, degeneration scale, combined HNP, and early ambulation. If we use the predicting score, we can postulate the occurrence of early recurrence after PELD. Knowing the predictive factors prior to surgical intervention will allow us to decrease the early recurrence rate after PELD.

## 1. Introduction

Recently, percutaneous endoscopic lumbar discectomy (PELD) has been popularized as an alternative to the traditional open discectomy. Like other surgical techniques, minimally invasive spine surgery is becoming the preferred method for both spinal surgeons and patients undergoing surgery for symptomatic lumbar disc herniation. In general, PELD has been performed by two common working pathways such as the transforaminal and interlaminar approach.

Although good surgical outcomes of PELD have been reported in many literatures for the treatment of various lumbar disc herniations, many surgeons are still experiencing endoscopic operative failure [1–10].

Endoscopic operative failure was defined as: (1) intracanal lower lumbar (L3–L4, L4–L5, and L5–S1) disc herniation that required subsequent surgery because of persistent symptoms within 2 weeks after surgery; (2) no pain-free interval from the first operation to the subsequent procedure; and (3) verification of remnant fragments by radiologic studies [11].

One of the most common complication after PELD is recurrent disc herniation. Recurrent lumbar disc herniation is defined as the recurrence of disc herniation at the same site of a previous discectomy, after an initial period of symptomatic improvement. This represents a significant complication of surgical failure, occurring in approximately 5–11% of discectomies [12–15].

We defined early recurrence as the recurrence of disc herniation within 6 months after PELD with a successful pain-free interval and complete removal of the protruding disc by follow-up MRI. The purpose of this study was to evaluate the risk factors related to early recurrence after PELD.

## 2. Materials and Methods

### 2.1. Materials

*2.1.1. Patients.* Between May 2012 and November 2017, we retrospectively reviewed 300 patients with lumbar disc herniation and performed PELD. All patients were followed-up for at least 6 months. The exclusion criteria were patients who were lost to follow-up in less than 6 months and those with pathologic degenerative spine disease (e.g., spinal stenosis, spondylolisthesis, and synovial cyst).

The patients included in this study met the following inclusion criteria: (1) transforaminal approach: patients who had undergone a surgical procedure above the L4–L5 level and interlaminar approach: patients who had undergone a surgical procedure at the L5–S1 level, (2) postoperative MRI showed complete removal of the protruded disc, (3) recurred radiculopathic leg pain after successful symptom-free interval at least longer than 2 weeks, (4) follow-up MRI showed newly developed disc protrusion in the previously operated site.

Patients were classified into three categories according to the endoscopic approach as follows: (1) group A: transforaminal inside-out approach, (2) group B: transforaminal outside-in approach, and (3) group C: interlaminar approach (Table 1, Figure 1).

Table 1: Classification of group of percutaneous endoscopic lumbar discectomy according to approach method.

| Group | Number | Approach |
|---|---|---|
| Group A | 100 | Transforaminal (Inside-out) |
| Group B | 100 | Transforaminal (Outside-in) |
| Group C | 100 | Interlaminar |

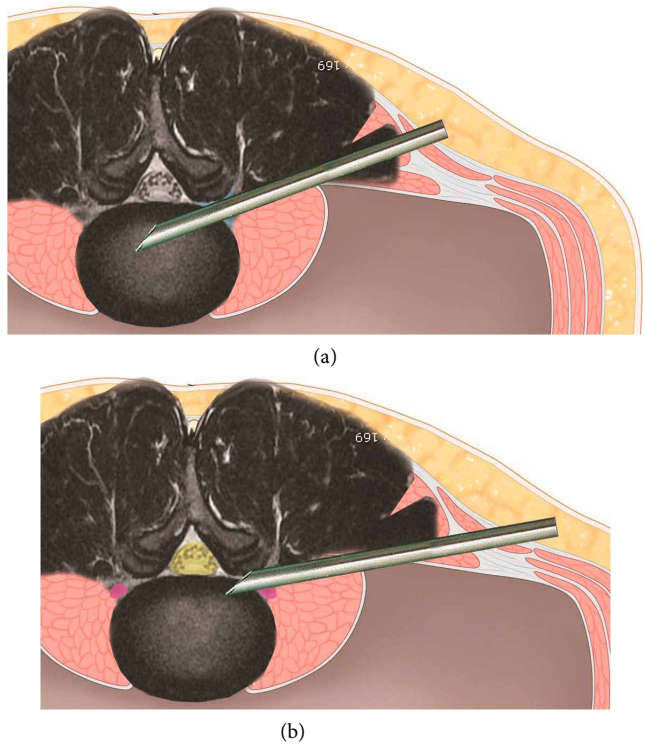


Figure 1: Transforaminal Inside-out and Outside-in technique. The technique of endoscopic transforaminal approach can be divided into the inside-out or outside-in techniques, based on the sequence method of whether the working channel was inserted into the disc space first (a) and then approaches the epidural space (out of disc space) later or in a reverse order (b).

All endoscopic surgeries were performed by an expert surgeon with at least over 5 years and 500 cases of experience in endoscopic surgery. Possible risk factors for early recurrence of lumbar disc herniation were retrospectively evaluated and included the following: Demographic factors (age, sex, and body mass index); Anatomical factors (disc degeneration scale, Modic change, number of disc herniation, history of discectomy, disc location, herniated disc level, disc height, and segmental dynamic motion), operation factors (annulus preservation, transforaminal inside-out vs outside-in vs interlaminar approach) and postoperative care factors (early ambulation, spinal orthosis).

*2.1.2. Follow-Up and New Symptomatic Relapsed Disc Herniation.* Patients were followed-up regularly at 2 weeks, 1 month, and every 3 months during the first year after the procedure and then on a yearly basis.

*2.1.3. Review of Patient Data.* Possible risk factors for new symptomatic recurrent disc herniation were retrospectively evaluated and included the following: demographic factors (age, sex, and BMI); disc factor (disc degeneration scale, modic change, number of disc herniation, history of discectomy, disc location, herniated disc level, disc height, and segmental dynamic motion); operation factors (annulus preservation, inside-out/outside-in approach); and postoperative care factors (early ambulation, spinal orthosis).

Based on this data, we developed a predictive scoring system to evaluate the risk of an early recurrent disc herniation.

We attempted to develop a scoring system for predicting recurrent lumbar disc herniation based on the collected data. We analyzed the data of individuals who had previous endoscopic discectomy and those with sufficient information. All radiographic information was extracted from the medical record system including disc degeneration scale, combined disc, herniated disc level, disc height, and segmental dynamic motion in the recurrent herniated disc levels. We obtained all the values of the segmental dynamic motion from the lumbar flexion/extension lateral image before reoperation.

In the evaluation of various parameters, we assigned the following points based on the (1) age (0 point: <40 years, 2 points: 40–60 years, 0 point: >60 years); (2) gender (0 point: male, 0 point: female); (3) BMI (0 point: <25 kg/m$^2$, 1 point: 25–30 kg/m$^2$, 2 points: >30 kg/m$^2$); (4) disc degeneration scale (0 point: grade 1–2, 1 point: grade 3, 2 points: grade 4–5); (5) modic change scale (0 point: no modic change, 1 point: type II or III, 2 points: type I); (6) number of involved disc herniation (0 point: 1 level, 1 point: 2 levels, 2 points: 3 levels, 3 points: 4 levels); (7) history of discectomy (0 point: first, 0 point: more than second); (8) disc location (1 point: central, 0 point: foraminal or far lateral, 2 points: paracentral, 3 points: sequestrated migration); (9) herniated disc level (0 point: L1–L2, L2–L3, or L3–4, 1 points: L4–L5); (10) disc height (2 points: <80%, 1 point: 80–100%, 0 point: >100%); (11) segmental dynamic motion (0 point: groups 1–10, 0 point: groups 11–20); (12) annulus preservation (0 point: minimal annulotomy, 1 point: radical resection); (13) early ambulation (1 points: early ambulation, 0 point: bed rest); (14) spinal orthosis (corset) application (0 point: corset applied, 1 point: no corset).

*2.1.4. Early Recurrence of Scoring System after Endoscopic Lumbar Discectomy.* According to the total summation of points, we classified all the subjects into four groups groups (I, II, III, and IV) and investigated the correlation of risk for early recurrence. Each group and early recurrence rates were comparatively analyzed (Figures 2 and 3).

*2.1.5. Statistical Analysis.* Age, gender, BMI, disc degeneration scale, Modic change, combined disc, herniated disc level, disc height, segmental dynamic motion in the recurrent herniated disc levels, early ambulation, and spinal orthosis were recorded. Baseline comparisons were performed using the paired $t$-test; chi-squared test, and risk factors for early recurrent disc herniation were analyzed using the logistic

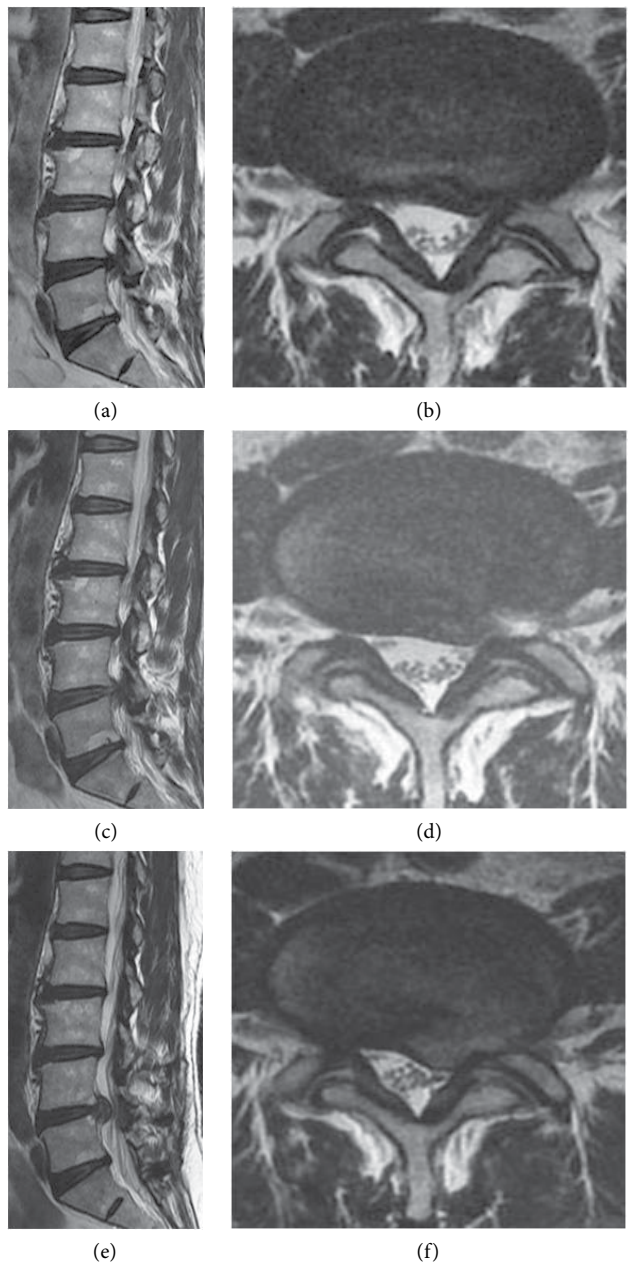



Figure 2: Case of early recurrence after PELD. Preoperative MRI shows L4–5 disc herniation left paracentral and foraminal type (a, b). Immediate postoperative MRI image shows L4–5 left side disc removed and left nerve root decompressed (c, d). However, 4 month later, follow-up MRI shows L4–5 disc reherniation again at same operated site (e, f). According to scoring system, (1) age: 47 (2 point), (2) gender: male (0 point), (3) BMI: 28.3 kg/m$^2$ (1 point), (4) disc degeneration scale: 3 scale (1 point), (5) Modic change (0 point), (6) combined HNP: 2 level (1 point), (7) disc herniation episode: first (0 point), (8) annulus preservation: minimal annulotomy (0 point), (9) approach: transforaminal outside-in (0 point) (10) disc location: paracentral (2 points) (11) herniated disc level: L4–5 (1 point), (12) disc height: 80–100% (0 point), (13) segmental dynamic motion: group 5 (0 point), (14) early ambulation: walking within 2 days (1 point), (15) spinal orthosis: no corset (1 point). Total score: 10 points (group C).

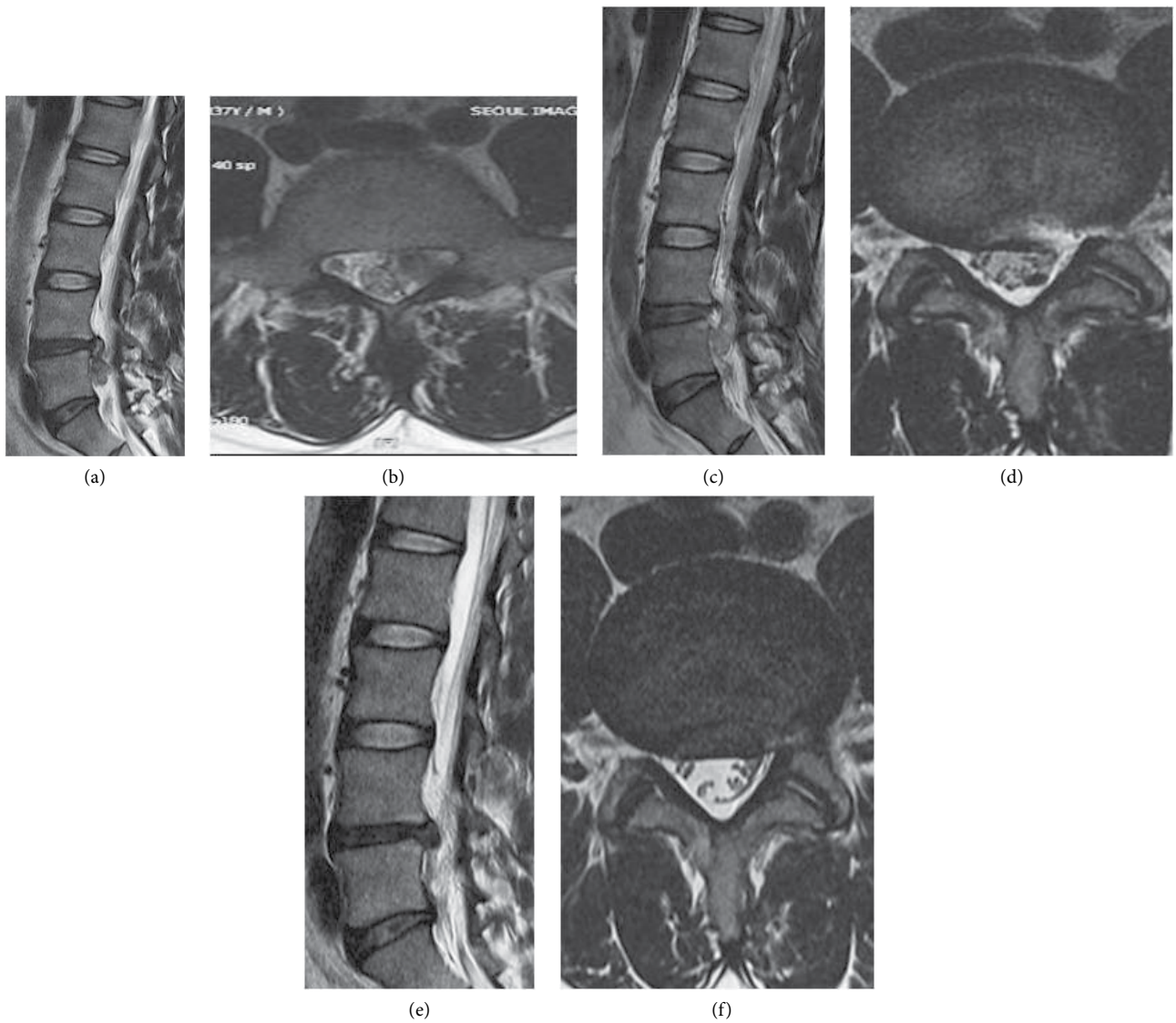


Figure 3: Case of early recurrence after PELD. Preoperative MRI shows L4–5 disc herniation left downward migrated type (a, b). Immediate postoperative MRI image shows L4–5 left side disc removed and left nerve root decompressed (c, d). However, 4 month later, follow-up MRI shows L4–5 disc reherination again at same operated site (e, f). According to scoring system, (1) age: 55 (2 point), (2) gender: female (0 point), (3) BMI: 23 kg/m$^2$ (0 point), (4) disc degeneration scale: 3 scale (1 point), (5) modic change (0 point), (6) combined HNP: 1 level (0 point), (7) disc herniation episode: first (0 point), (8) annulus preservation: minimal annulotomy (0 point), (9) approach: transforaminal outside-in (0 point) (10) disc location: paracentral downward migrated (2 points) (11) herniated disc level: L4–5 (1 point), (12) disc height: 66% (1 point), (13) segmental dynamic motion: group 7 (0 point), (14) early ambulation: bed resting 5 days (0 point), (15) spinal orthosis: corset (0 point). Total score: 7 points (group B).

regression test. SPSS ver. 15.0 software (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses, and $P$-values $< 0.05$ were considered statistically significant.

## 3. Results

A total of 300 patients (group A: 100, group B: 100, group C: 100) were enrolled in this study. There were 139 males and 161 females. The mean age was 46.72 ± 15.24 years (range 19–93 years) and the mean follow-up duration was 35.5 months (range, 6–75 months). The average age was 46.51 ± 18.14 years for group A, 45.65 ± 15.08 years for group B and 47.29 ± 14.56 years for group C (Table 2).

The mean follow-up period for each group was 21.12 ± 4.57 months in group A, 12.54 ± 3.41 months in group B, and 19.00 ± 4.42 months in group C. The total early recurrence rate after PELD was 9.33% (28/300), and the recurrence rate in each group was 11% (11/100) for group A, 10% (10/100) for group B, and 7% (7/100) for group C. Overall, the mean recurrence time after disc removal was 3.26 months.

The changes of the visual analogue scale (VAS) score before and after endoscopic surgery improved from 8.18 ± 0.78 preoperatively to 1.55 ± 1.0 postoperatively, 9.07 ± 0.77 to 1.39 ± 2 0.92 in group A, 8.34 ± 0.50 to 1.34 ± 0.93 in group B, and 8.14 ± 0.82 to 1.86 ± 1.09 in group C (Table 2).

Table 2: Surgical Outcome and Recurrence Rate according to the endoscopic approaching method.

| Group | Follow-up (months) | Mean age | Recurrence | Pre-OP VAS | Post-OP VAS |
|---|---|---|---|---|---|
| Group A | 21.12 ± 4.57 | 46.51 ± 18.14 | 11% (11/100) | 8.07 ± 0.77 | 1.39 ± 0.92 |
| Group B | 12.54 ± 3.41 | 45.65 ± 15.08 | 10% (10/100) | 8.34 ± 0.50 | 1.34 ± 0.93 |
| Group C | 19.0 ± 4.42 | 47.29 ± 14.56 | 7% (7/100) | 8.14 ± 0.82 | 1.86 ± 1.09 |

*3.1. Early Recurrence Rates after PELD.* Of the 300 patients who were followed-up, early recurrence occurred in 28 cases (9.3%) after PELD.

The recurrence rate after removal of the discs using the transforaminal approach was 10.5% (21/200) for groups A and B and 7% (7/100) for group C using the interlaminar approach. Overall, the mean recurrence time after disc removal was 3.58 months. The early recurrence rate was higher in the group using the transforaminal approach (groups A and B) than in the group using the interlaminar approach (group C); however, there was no difference in the surgical approach method.

*3.2. Changes in VAS.* After PELD, the preoperative pain reduced significantly. Moreover, irrespective of the endoscopic approach used, the postoperative VAS score was reduced significantly in all groups [mean preoperative VAS vs postoperative VAS: group A, 8.07 ± 0.77 vs. 1.39 ± 0.92; group B, 8.34 ± 0.50 vs. 1.34 ± 0.93; and group C, 8.14 ± 0.82 vs. 1.86 ± 1.09 ($P \leq 0.05$) (Table 2).

*3.2.1. Demographic Factors*

*(1) Age and Gender.* The early recurrence rate was related to age. Relatively high recurrence rates (20/124, 16.1%) were seen in patients between 40 and 60 years of age. A similar recurrence rate was observed in the groups below 40 years old (6/115, 5.22%) and those over 60 years old (2/65, 3.07%). There was no statistically significant difference in the early relapse rate for age and gender: male (13/139, 9.35%) vs. female (15/161, 9.32%) ($P > 0.05$) (Table 3).

*(2) Body Mass Index (BMI).* The early recurrence rate was related to BMI which is a simple calculation using a person's height and weight. The formula is BMI = kg/m$^2$ where kg is a person's weight in kilograms and m$^2$ is their height in meters squared. BMI ranges are underweight: <18.5 kg/m$^2$, normal weight: 18.5–25 kg/m$^2$, overweight: 25–30 kg/m$^2$, and obese: >30 kg/m$^2$. Relatively high recurrence rates were seen in the obese (13/74, 17.57%) and overweight (9/77, 11.69%) patients. A similar recurrence rate was observed in the underweight (4/63, 6.35%) and normal-weight (2/86, 2.33%) patients ($P \leq 0.05$) (Table 3).

*3.2.2. Anatomical Factors*

*(1) Disc Degeneration Scale.* In the present study, according to the grading system of Pfirrmann et al. [16], we classified the disc degeneration scale into the following three scales: 1 scale (mildly degenerated), 2 scale (moderately degenerated), and 3 scale (severely degenerated: completely blackened). The classification by Pfirrmann et al. [16] is useful in assessing the degrees of disc degeneration on T2-weighted images: grade 1 (normal shape, no horizontal bands, clear distinction of the nuclei and annuli), grade 2 (nonhomogeneous shape with horizontal bands, some blurring between the nuclei and annuli), grade 3 (nonhomogeneous shape with blurring between the nuclei and annuli, annuli shape is still recognizable), grade 4 (nonhomogeneous shape with hypointensity, annuli shape is not intact and distinction between the nuclei and annuli is impossible, disc height is usually decreased), and grade 5 (same as grade 4 but with collapsed disc space). Grades 1 to 2 were classified as normal discs, while grades 3 to 5 were defined as degenerative.

Early disc recurrence showed a good relation with the disc degeneration scale; the greater the disc degeneration scale, the more frequently disc herniation recurred. Two percent (1 out of 50 cases) of early recurrent disc herniation occurred in patients with grades 1 to 2 disc degeneration. Meanwhile, 7.4% (10 of 135 cases) and 14.8% (17 of 115 cases) in the disc degeneration of 3 grade and 4–5 grade ($P \leq 0.05$) (Table 3).

*(2) Modic Change.* The early disc recurrence rate increased in Modic change. Modic changes are pathological changes in the bones of the spine and the vertebrae. These changes are situated both in the vertebral body and in the end plate of the neighboring disc. In Modic type I, there is vascular development in the vertebral body, with findings of inflammation and edema, but no trabecular damage or marrow changes. In Modic type II, there are changes in the bone marrow, with fatty replacement of formerly red, cellular marrow normally seen there. In Modic type II, the marrow is substituted by the visceral fat, the same kind of fat we have on our hips and bellies. Modic type III changes are less common, with fractures of the trabecular bone, along with trabecular shortening and widening.

In our study, there are 22% (5/22 cases) of early recurrence rate in the Modic change group; 25% (3/12 cases), 14.3% (1/7 cases), and 33% (1/3 cases) showed type I, II, and III Modic change, respectively; however, only 8.27% (23/278 cases) showed disc recurrence for no Modic change group ($P > 0.05$) (Table 3).

*(3) Number of Involved Disc Herniation.* The early disc relapse rate increased in proportion to the number of involved disc herniation levels. About 10.4% (13/125 cases), 18.9% (7/37 cases), and 30% (3/10 cases) showed early relapse in 2, 3, and 4 levels of involved disc herniation cases, respectively; however, only 3.9% (5/128 cases) showed disc relapse for one involved level disc herniation ($P \leq 0.05$) (Table 3).

*(4) History of Surgery for Disc Herniation.* The early recurrence rate was 8.83% (25/283) in patients who underwent endoscopic discectomy for the first time after being diagnosed with

Table 3: Early recurrence rate according to factors after Percutaneous endoscopic lumbar discectomy.

| | Factors | Group | Recurrence rate | Score | Relation | ($P=$ ) |
|---|---|---|---|---|---|---|
| Demographic factors | Age | ~40 | 6/115 (5.22%) | 0 | No | 0.824 |
| | | 41~60 | 20/124 (16.1%) | 2 | | |
| | | 61~ | 2/65 (3.07%) | 0 | | |
| | | Total | 28/300 (9.3%) | | | |
| | Gender | Male | 13/139 (9.35%) | 0 | No | 0.956 |
| | | Female | 15/161 (9.32%) | 0 | | |
| | | Total | 28/300 (9.3%) | | | |
| | BMI (kg/m2) | <18.5 kg/m2 | 4/63 (6.35%) | 0 | Yes | 0.045 |
| | | 18.5~25 | 2/86 (2.33%) | 0 | | |
| | | 25~30 | 9/77 (11.69%) | 1 | | |
| | | >30 | 13/74 (17.57%) | 2 | | |
| | | Total | 28/300 (9.3%) | | | |
| Anatomical factors | Disc degeneration scale | Grade 1–2 (mild) | 1/50 (2%) | 0 | Yes | 0.018 |
| | | 3 scale (moderate) | 10/135 (7.4%) | 1 | | |
| | | 4–5 (severe) | 17/115 (14.8%) | 2 | | |
| | | Total | 28/300 (9.3%) | | | |
| | Modic change | Type I | 3/12 (25%) | 0 | No | 0.153 |
| | | Type II | 1/7 (14.3%) | 0 | | |
| | | Type III | 1/3 (33%) | 0 | | |
| | | Total | 5/22 (22%) | | | |
| | Number of involved disc herniation | One level | 5/128 (3.9%) | 0 | Yes | 0.001 |
| | | Two level | 13/125 (10.4%) | 1 | | |
| | | Three level | 7/37 (18.9%) | 2 | | |
| | | Four level | 3/10 (30%) | 3 | | |
| | | Total | 28/300 (9.3%) | | | |
| | History of discectomy | First | 25/283 (8.83%) | 0 | No | 0.236 |
| | | Reoperation | 3/17 (17.65%) | 1 | | |
| | Location of disc herniation | Paracentral (including sequestrated disc) | 24/207 (11.59%) | 2 | No | 0.306 |
| | | Central | 2/27 (7.41%) | 1 | | |
| | | Foraminal and extraforaminal | 2/66 (3.03%) | 0 | | |
| | | Total | 28/300 (9.3%) | | | |
| | Level of disc herniation | Upper disc (L1–2, L2–3, L3–4) | 3/76 (3.95%) | 0 | Yes | 0.174 |
| | | L4–5 | 18/123 (14.6%) | 2 | | |
| | | L5–S1 | 7/100 (7%) | 1 | | |
| | | Total | 28/300 (9.3%) | Total | | |
| | Disc height | Less than 80% | 6/35 (17.14%) | 1 | No | 0255 |
| | | 80~100% | 12/147 (8.16%) | 0 | | |
| | | Larger | 10/118 (8.5%) | 0 | | |
| | | Total | 28/300 (9.3%) | | | |
| | Segmental dynamic motion | Group 1~10 | 20/233 (8.58%) | 0 | No | 0.558 |
| Operation factors | Approach method | Transforaminal (Inside-out) | 11/100 (11%) | 0 | No | |
| | | Transforaminal (Outside-in) | 10/100 (10%) | 0 | | |
| | | Interlaminar | 7/100 (7%) | 0 | | |
| | Annlus preservation | Radical annulotomy | 21/213 (9.86%) | 0 | No | 0.625 |
| | | Minimal annulotomy | 7/87 (8.05%) | | | |
| | | Total | 28/300 (9.3%) | | | |
| | | Group 11~20 | 8/67 (11.9%) | 0 | | |
| Postoperative factors | Early ambulation | Walking within 2 days | 23/140 (16.42%) | 1 | Yes | 0.001 |
| | | Bed rest longer than 3 days | 5/160 (3.13%) | 0 | | |
| | Orthosis application | Corset apply | 10/136 (7.35%) | 0 | Yes | 0.286 |
| | | No corset | 18/164 (10.98%) | 1 | | |
| Early recurrence rate according to the scoring system | | | | | Yes | 0.001 |

herniated disc and 17.65% (3/17) in patients who underwent endoscopic reoperation after the past surgery. There was no statistically significant difference between the two groups ($P > 0.05$) (Table 3).

*(5) Location of Disc Herniation.* The recurrence rate after PELD according to the type of disc location was commonly found in the paracentral type of disc herniation followed by the central and far lateral types. In particular, 11.59% (24/207 cases) showed early recurrence in the paracentral type (including superior or inferior migration type) of disc herniation. However, only 7.41% (2/27 cases) and 3.03% (2/66 cases) showed early recurrence in the central type and foraminal type (including extraforaminal type) disc herniation, respectively ($P > 0.05$) (Table 3).

*(6) Level of Disc Herniation.* The rate of recurrence was significantly higher in L4–L5 than in the upper lumbar disc herniation. Early recurrence rate was 14.6% (18/123) in cases of L4–L5 disc herniationn, 7.0% (7/100) in L5–S1 and 3.95% (3/76) in cases of upper lumbar disc herniation (L1–L2, L2–L3, L3–L4) ($P > 0.05$) (Table 3).

*(7) Disc Height.* Early disc relapse showed good relation with the disc height; the smaller the disc height, the more frequently disc herniation recurred. About 17.14% (6 out of 35 cases) of early recurrence occurred in the cases with less than 80% of normal disc height. Meanwhile, 8.16% (12 out of 147 cases) and 8.5% (10 out of 118 cases) of early recurrence occurred in the cases with 80–100% of normal disc height and in the cases with larger than normal disc height ($P > 0.05$) (Table 3).

*(8) Segmental Dynamic Motion.* Early recurrence rate was 8.58% (20/233) in group between 1 and 10 of segmental dynamic motion and 11.9% (8/67) in group between 11 and 20 of segmental dynamic motion. There was no statistically significant difference between the two groups ($P > 0.05$) (Table 3).

*3.2.3. Operation Factors*

*(1) Approaching Method.* The total early recurrence rate after PELD was 9.33% (28/300), and the recurrence rate in each group was 11% (11/100) for group A, 10% (10/100) for group B, and 7% (7/100) for group C. The recurrence rate of the group using the transforaminal approach was 12% (21/200) for groups A and B and that using the interlaminar approach was 7% (7/100) for group C. The early recurrence rate was higher in the group using the transforaminal approach (groups A and B) than in the group using the interlaminar approach (group C); however, there was no significant difference in the surgical approach method (Table 3).

*(2) Annulus Preservation.* The early recurrence rate was 8.05% (7/87) in cases of endoscopic discectomy preserving the annulus without radical annulotomy and 9.86% (21/213) in cases of endoscopic discectomy with radical annulotomy. There was no statistically significant difference between the two groups ($P > 0.05$) (Table 3).

*3.2.4. Postoperative Care Factor*

*(1) Early Ambulation.* Early ambulation is a technique in the postoperative care in which a patient gets out of bed and engages in light activity (such as sitting, standing, or walking) as soon as possible after an operation. Early ambulation was possible after 1 day.

Early recurrence rate was 16.42% (23/140) in the early ambulation group and 3.13% (5/160) in the group with bed rest longer than 3 days after surgery ($P \leq 0.005$) (Table 3).

*(2) Orthosis Application.* Corsets were used to wear orthoses, and they were worn immediately after surgery and were compared with nonwearing groups. Early recurrence rate was 7.35% (10/136) in the corset group and 10.98% (18/164) in the noncorset group ($P > 0.05$) (Table 3).

*3.3. Early Recurrence Rate according to the Scoring System.* Based on the factors related to early recurrences including the age, gender, disc degeneration, combined disc herniation, disc herniation history, disc location (central, foraminal or far lateral, paracentral, and sequestrated migration), annulus preservation, herniated disc level, disc height, and segmental dynamic motion, we developed the scoring system and applied it to all cases of early recurrence. We classified all cases into four groups (I, II, III, IV) according to the early recurrence score. Groups I, II, III, and IV were defined by total scores of 0–4, 4–8, 9–12, and 13–16, respectively.

According to early recurrence score, groups I, II, III, and IV showed an early recurrence rate of 0% (0/32 cases), 7.1% (13/183 cases), 8.0% (6/75 cases), and 100% (10/10 cases) (Figures 2 and 3).

Therefore, the total score had a close relation with the risk of early recurrence of disc herniation after endoscopic lumbar discectomy. Groups I, II, III, and IV could be classified as low risk, mild~ moderate risk, high risk groups, respectively ($P \leq 0.05$) (Table 4).

## 4. Discussion

Recurrent lumbar disc herniation is defined as a recurrence of disc herniation at the same site of a previous discectomy in a patient who has experienced a pain-free interval after surgery. However, the minimum length of the pain-free interval is debatable, ranging from any interval of pain resolution to 6 months [15, 17].

Moreover, recurrent disc herniation should be discriminated from incomplete discectomy or endoscopic operative failure.

Lee et al. [11] reported endoscopic operative failure as: (1) intracanal lower lumbar (L3–L4, L4–L5, and L5–S1) disc herniation that required subsequent surgery because of persistent symptoms within the 2 weeks after surgery; (2) no pain-free interval from the first operation to the subsequent procedure; and (3) verification of remnant fragments by radiologic studies.

We defined the early recurrence of disc herniation after PELD as a recurrence of disc herniation within 6 months after at least 2 weeks of successful pain-free interval with complete removal of the protruding disc by follow-up MRI.

Several studies reported that the recurrent disc herniation represents a significant cause of surgical failure, occurring in approximately 5–11% of discectomies [12–15]. The recurrence rate after PELD has been reported to be 0%–7.4% [17–20]. Some researchers showed that there was no

Table 4: Early recurrence rate according to groups of predictive recurrence score.

| Group | Total score | Early recurrence rate | Risk of early recurrence |
|---|---|---|---|
| Group I | 0~4 | 0% (0/32) | Low |
| Group II | 4~8 | 7.1% (13/183) | Mild~moderate |
| Group III | 8~12 | 8.0% (6/75) | Mild~moderate |
| Group IV | 12~16 | 100% (10/10) | High |

significant difference in the recurrence rate between open surgery and PELD [21, 22].

Kim et al. [23] reported old age, high BMI, protrusion type of disc herniation, and positive Modic changes as risk factors after percutaneous endoscopic discectomy.

Swartz and Trost [24], however, found that age, gender, smoking status, level of herniation, and duration of symptoms were not associated with RLDH.

Yao et al. [25] reported that obesity (BMI $\geq 25\,kg/m^2$) was the most robust risk factor responsible for recurrence after PELD. Also, they insisted that older age (≥50 years old), learning curve of the surgeon (<200 cases), treatment period (March 2005 to September 2010), and central location of herniation were closely associated with recurrent herniation after successful PELD.

In our department, the early recurrence rate after successful PELD between March 2005 and March 2016 was 9.5%. Revision surgery is necessary for patients who fail to respond to conservative therapy. To explore independent risk factors for early relapse after PELD, data from 300 patients with after PELD were analyzed, and life factor (age, sex); disc factor (disc degeneration scale, combined disc, disc herniation event); operation factor (disc location, annulus preservation, and inside-out/outside-in approach); and segmental stability factor (herniated disc level, disc height, and segmental dynamic motion).

Unlike other reports, in our study, early recurrence rate was relatively high in the middle age groups (40–60 years) than in young and old age groups. The reason for the high early recurrence rate in the middle age group is that physical activity is similar to that of the younger age group; however, there is more degenerative disc change in the young age group. On the other hand, physical activity is higher than that of old age group with similar degenerative disc change. Also, another reason for the high recurrence rate in the age group of 40 ~ 60s is that the stenosis increases rapidly in the 60s, however, in this study, the spinal stenosis is excluded.

The previous clinical studies indicated that an age of more than 40 years was a predisposing factor to failure of the operation [3]. Older discs generally have a greater degree of degenerative changes, and the remaining discs after discectomy are more susceptible to mechanical damage due to physical load on the incision site. The disc degeneration grade proposed by Pfirrmann et al. [16] was statistically significant in the recurrent group in contrast to the nonrecurrent group; the greater the disc degeneration scale, the more frequently disc herniation recurred. These findings provide evidence that the healing processes that occur in the outer lamellae after annular injury may not be sufficient for effective reconstitution of the external annulus in degenerated discs [26, 27].

The result of this study showed that patients with combined multi-level disc herniation were more likely to experience recurrent disc herniation compared to patients with single-level disc herniation. It is reasonable that multi-level intervertebral disc herniation typically has a higher disc degeneration, and the remaining intervertebral disc damaged during surgery can easily prolapse in response to mechanical overload.

However, the number of previous discectomies is not related to the early relapse of disc herniation. If discectomy is successful, the number of previous operations will not increase the recurrence rate.

The results of this study showed that patients with paracentral disc herniation were more likely to experience early relapse compared to patients with central and far lateral herniation. Yao et al. [25] reported that patients with central herniation were more likely to experience recurrent herniation compared to patients with paramedian herniation. They believed that the role of this risk factor is highly related to the choice of the working channel position. The key point of PELD is to place the working channel near the herniated content. For the treatment of central herniation, the working channel is placed inside the nucleus pulposus with a very steep trajectory angle. As a result, the ruptured intervertebral disc is not easily accessible. However, this is contradictory to our opinion. For the central disc herniation, the working channel should be placed inside the nucleus pulposus with a more horizontal trajectory angle. Using this approach we could remove more centrally located disc herniation aggressively. However, in the cases of paracentral and far lateral disc herniation, approaching trajectory should be more vertical.

We believe that this difference in approaching trajectory makes the range and amount of discs that can be removed different, and the remnant disc material would be an important role of recurrence after PELD.

The degree of removal of the annulus fibrosus during discectomy may vary from person to person. In our study, the method of extracting the nucleus by putting the forceps through only the small hole of the annulus did not reduce the early relapse rate compared to the removal of the annulus fibrosus. Perhaps, the smaller the hole in the annulus, the higher the pressure in the disc space would be. Hence, there seems to be no difference between the two groups.

The technique of endoscopic transforaminal approach can be divided into the inside-out or outside-in techniques, based on the sequence method of whether the working channel was inserted into the disc space first and then approaches the epidural space (out of disc space) later or in a reverse order.

The inside-out technique is a method of removing the herniated disc by inserting the working sheath into the disc space and performing the discectomy, which is advantageous for the beginner. In contrast, the outside-in technique start from docking the working sheath in the extradiscal space of the safety zone and then approaching to the epidural space. This technique is advantageous method for aminoplasty to remove the migrated disc herniation in narrowed safety zones.

However, there is no difference in the recurrence rate between the two groups. In fact, many of the experienced

surgeons were able to change two methods according to the surgical situation, and there was no difference in the results.

L4–L5 is the most common early recurrence site because it is the most weight loaded level. However, the number of cases of PELD was overwhelming at L4–L5. Therefore, it is believed that there is a statistical limit to compare with recurrence rates of other levels.

Our study showed that preoperative intervertebral disc heights were statistically not significant in early recurrent disc herniation ($P = 0.255$). However, disc collapsed height was less than 80% showed twice recurrent rate. Especially disc collapsed height was less than 80% showed twice recurrent rate. Axelsson et al. [28] reported that degenerative segments with preserved disc height have a latent instability compared to segments with collapsed discs. Hasegawa et al. [29] reported that the restabilization stage begins when the disc height is reduced by 50%.

Early ambulation and orthosis application may affect the recurrence rate of lumbar intervertebral disc herniation after endoscopic discectomy. This suggests that the body weight is repeatedly applied to the remaining nucleus in the partially removed disc space. This will increase the risk of recurrence of the disc herniation by increasing the disc pressure. It is believed that wearing corset to disperse body weight will reduce the load on the nucleus pulposus and lower the pressure in the intervertebral disc to prevent recurrent disc herniation. However, corset wearing has limitation to prevent early recurrent disc herniation.

## 5. Conclusion

The early recurrent disc herniation after PELD is defined as recurrence of disc herniation within 6 months after successful pain-free interval for at least 2 weeks and complete removal of the protruding disc by follow-up MRI. It is associated with several factors such as BMI, degeneration scale, combined HNP, and early ambulation. Except for the operation factor and segmental instability factor, Life factor and postoperative factor affect the recurrence. That is, the operation factor has no significant effect on recurrence.

It may play an important role in the failure of endoscopic surgery. According to our scoring system, the total score was associated to the risk of early recurrence of disc herniation after endoscopic lumbar discectomy. If the score is high, the patients have a greater chance of early recurrence. Therefore, more attention must be provided to such patients; indeed, providing education with respect to strict bed rest, spinal bracing. Knowing the predictive factors prior to surgical intervention will allow us to decrease the early relapse rate after PELD.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

Jong Duck You and Hyeun Sung Kim have the same contribution to the paper.

## Acknowledgments

This work was supported by AOSpine Research Grant 2017. This paper was presented in the conference of ISASS 2013.

## References

[1] A. T. Yeung, "The evolution of percutaneous spinal endoscopy and discectomy: state of the art," *Mount Sinai Journal of Medicine*, vol. 67, no. 4, pp. 327–332, 2000.

[2] A. T. Yeung and P. M. Tsou, "Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases," *Spine*, vol. 27, no. 7, pp. 722–731, 2002.

[3] Y. Ahn, S.-H. Lee, W.-M. Park, H.-Y. Lee, S.-W. Shin, and H.-Y. Kang, "Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases," *Spine*, vol. 29, no. 16, pp. E326–E332, 2004.

[4] F. U. Hermantin, T. Peters, L. Quartararo, and P. Kambin, "A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy," *The Journal of Bone and Joint Surgery*, vol. 81, no. 7, pp. 958–965, 1999.

[5] P. Kambin, K. Casey, E. O'Brien, and L. Zhou, "Transforaminal arthroscopic decompression of lateral recess stenosis," *Journal of Neurosurgery*, vol. 84, no. 3, pp. 462–467, 1996.

[6] M. T. N. Knight, D. R. Ellison, A. Goswami, and V. F. Hillier, "Review of safety in endoscopic laser foraminoplasty for the management of back pain," *Journal of Clinical Laser Medicine and Surgery*, vol. 19, no. 3, pp. 147–157, 2001.

[7] M. T. Knight, A. Goswami, J. T. Patko, and N. Buxton, "Endoscopic foraminoplasty: a prospective study on 250 consecutive patients with independent evaluation," *Journal of Clinical Laser Medicine and Surgery*, vol. 19, no. 2, pp. 73–81, 2001.

[8] M. T. Knight, A. Vajda, G. V. Jakab, and S. Awan, "Endoscopic laser foraminoplasty on the lumbar spine-early experience," *Minimally Invasive Neurosurgery*, vol. 41, no. 1, pp. 5–9, 1998.

[9] S. M. Lew, T. F. Mehalic, and K. L. Fagone, "Transforaminal percutaneous endoscopic discectomy in the treatment of far-lateral and foraminal lumbar disc herniations," *Journal of Neurosurgery: Spine*, vol. 94, no. 2, pp. 216–220, 2001.

[10] H. M. Mayer and M. Brock, "Percutaneous endoscopic lumbar discectomy (PELD)," *Neurosurgical Review*, vol. 16, no. 2, pp. 115–120, 1993.

[11] S. H. Lee, B. U. Kang, Y. Ahn et al., "Operative failure of percutaneous endoscopic lumbar discectomy: a radiologic analysis of 55 cases," *Spine*, vol. 31, no. 10, pp. 285–290, 2006.

[12] M. S. Patel, J. Braybrooke, M. Newey, and P. Sell, "A comparative study of the outcomes of primary and revision lumbar discectomy surgery," *The Bone & Joint Journal*, vol. 95-B, no. 1, pp. 90–94, 2013.

[13] G. Cinotti, G. S. Roysam, S. M. Eisenstein, and F. Postacchini, "Ipsilateral recurrent lumbar disc herniation. A prospective,

controlled study," *The Journal of Bone and Joint Surgery*, vol. 80, no. 5, pp. 825–832, 1998.

[14] J. Stambough, "An algorithmic approach to recurrent lumbar disk herniation: evaluation and management," *Seminars in Spine Surgery*, vol. 20, no. 1, pp. 2–13, 2008.

[15] K. R. Swartz and G. R. Trost, "Recurrent lumbar disc herniation," *Neurosurgical Focus*, vol. 15, no. 3, pp. 1–4, 2003.

[6] M. T. N. Knight, D. R. Ellison, A. Goswami, and V. F. Hillier, "Review of safety in endoscopic laser foraminoplasty for the management of back pain," *Journal of Clinical Laser Medicine and Surgery*, vol. 19, no. 3, pp. 147–157, 2001.

[17] T. Hoogland, M. Schubert, B. Miklitz, and A. Ramirez, "Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases," *Spine*, vol. 31, no. 24, pp. 890–897, 2006.

[18] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study," *Spine*, vol. 33, no. 9, pp. 931–939, 2008.

[19] K. C. Choi, J. S. Kim, B. U. Kang, C. D. Lee, and S. H. Lee, "Changes in back pain after percutaneous endoscopic lumbar discectomy and annuloplasty for lumbar disc herniation: a prospective study," *Pain Medicine*, vol. 12, no. 11, pp. 1615–1621, 2011.

[20] J. S. Jang, S. H. An, and S. H. Lee, "Transforaminal percutaneous endoscopic discectomy in the treatment of foraminal and extraforaminal lumbar disc herniations," *Journal of Spinal Disorders and Techniques*, vol. 19, no. 5, pp. 338–343, 2006.

[21] J. Cheng, H. Wang, W. Zheng et al., "Reoperation after lumbar disc surgery in two hundred and seven patients," *International Orthopaedics*, vol. 37, no. 8, pp. 1511–1517, 2013.

[22] C. H. Kim, C. K. Chung, C. S. Park, B. Choi, M. J. Kim, and B. J. Park, "Reoperation rate after surgery for lumbar herniated intervertebral disc disease: nationwide cohort study," *Spine*, vol. 38, no. 7, pp. 581–590, 2013.

[23] J. M. Kim, S. H. Lee, Y. Ahn, D. H. Yoon, C. D. Lee, and S. T. Lim, "Recurrence after successful percutaneous endoscopic lumbar discectomy," *Minimally Invasive Neurosurgery*, vol. 50, no. 2, pp. 82–85, 2007.

[24] K. R. Swartz and G. R. Trost, "Recurrent lumbar disc herniation," *Neurosurgical Focus*, vol. 15, no. 3, pp. 1–4, 2003.

[25] Y. Yao, H. Liu, H. Zhang et al., "Factors for recurrent herniation after percutaneous endoscopic lumbar discectomy," *World Neurosurgery*, vol. 100, no. 1–6, 2017.

[26] D. Hampton, G. Laros, R. McCarron, and D. Franks, "Healing potential of the anulus fibrosus," *Spine (Phila Pa 1976)*, vol. 14, no. 4, pp. 398–401, 1989.

[27] O. L. Osti, B. Vernon-Roberts, and R. D. Fraser, "1990 Volvo award in experimental studies. Anulus tears and intervertebral disc degeneration. An experimental study using an animal model," *Spine*, vol. 15, no. 8, pp. 762–767, 1990.

[28] P. Axelsson and B. S. Karlsson, "Intervertebral mobility in the progressive degenerative process. A radiostereometric analysis," *European Spine Journal*, vol. 13, no. 6, pp. 567–572, 2004.

[29] K. Hasegawa, K. Kitahara, T. Hara, K. Takano, H. Shimoda, and T. Homma, "Evaluation of lumbar segmental instability in degenerative diseases by using a new intraoperative measurement system," *Journal of Neurosurgery: Spine*, vol. 8, no. 3, pp. 255–262, 2008.

Hindawi
BioMed Research International
Volume 2019, Article ID 4583943, 8 pages
https://doi.org/10.1155/2019/4583943

*Review Article*

# A History of Endoscopic Lumbar Spine Surgery: What Have We Learnt?

**H. Michael Mayer** [1,2]

[1]*Spine Center, Schön Klinik München Harlaching, Academic Teaching Hospital, Harlachinger Str. 51, 81547 München, Germany*
[2]*Institute for Spinal Research, Paracelsus Medical University, Salzburg, Austria*

Correspondence should be addressed to H. Michael Mayer; mmayer@schoen-kliniken.de

Received 28 August 2018; Accepted 4 February 2019; Published 3 April 2019

Academic Editor: Eberval G. Figueiredo



The new development and finally the general acceptance of surgical techniques among the worldwide surgical community sometimes create fascinating stories. This is also true for the history of endoscopic lumbar spine surgery. In the last 100 years there was a "natural" evolution of surgical techniques with continuous improvement and "refinement" of lumbar decompression techniques towards less invasive operations with the final "endpoint" of microsurgery. However the application of percutaneous, image-guided, and endoscopic technologies has revolutionized minimally invasive surgery. This article describes the history of endoscopic lumbar spine surgery and its major milestones and protagonists which have helped to make endoscopic lumbar spine surgery "disruptive" minimally invasive surgical technology which has changed the world of lumbar decompression surgery.

*"The past is the mother of the future"*
*Henri Cartier Bresson, French Photographer, 1908-2004*

## 1. Introduction

Development and progress in spinal surgery have always been characterized by "back-and-forth movements" in clinical applications of technical innovations. Most evolutionary technical improvements which seemed to have a logical indication spectrum, with adequate feasibility and a perspective to improve early or late outcomes, have sooner or later become "standard" with a worldwide market penetration. A good example of such a development is anterior cervical discectomy and fusion (ACDF). It all started with the Cloward and Smith-Robinson technique [1, 2], which was improved with the development of plates [3–5] to support and fix the bone grafts. The bone grafts were replaced by cages made from different materials, and further technical improvement has led to the use of cages as stand-alone devices recently. This is a typical simple example of a continuous evolution of a surgical technique.

The lesson we can learn from this is that if a technical improvement follows the needs of the surgeon and if it improves or standardizes a surgical technique and its outcomes, the acceptance among the surgical community will be logical and high.

## 2. History of Lumbar Disc Surgery

*2.1. Part 1: From Complete Laminectomy to Microsurgical/Microendoscopic Techniques.* The history of lumbar discectomy and lumbar decompression is one of the most fascinating chapters of spine surgery which has taught us a number of important lessons.

It was in 1909 when Krause and Oppenheim described the first lumbar discectomy [6] (Figure 1). Erroneously they described the herniated disc as a chondroma of the lumbar spinal canal. Only 2 years later Goldthwaite and Middleton were the first to describe a herniated nucleus pulposus as a reason of low back pain and sciatica [7, 8](Figure 2)

And it took another 11 years until Adson came up with the first report about surgical removal of herniated nucleus pulposus [9](Figure 3).

Figure 1: F Krause and H Oppenheim: first surgical removal of a "chondroma" of the spinal canal 1909.

Figure 2: JE Goldthwaite: first description of herniated nucleus pulposus as reason for sciatica, 1911.

Figure 3: AW Adson: first description of surgical removal of herniated nucleus pulposus, 1922.

Figure 4: WJ Mixter: first case series of surgical removal of herniated discs 1934.

However, like very often in medical history the merits for the first disc surgeries went to two other colleagues, namely, Mixter and Barr, who still are considered as having been the "first disc surgeons" in 1934 [10] (Figure 4). They actually published the first series of successful disc operations in 1934. Their technique however was a complete laminectomy and some of the disc herniations were removed through a transdural approach.

It was obvious from the beginning that this was a very traumatic approach with the potential of a variety of complications including dural leaks and segmental instability as well as disabling back pain.

The search for less damaging approaches had started. Only 5 years later, Love described the first interlaminar approach [11] which became the standard procedure for many years (Figure 5). But even though the rate of major surgical complications dropped over time, the problem of postoperative back pain and rapid progression of disc degeneration due to aggressive disc removal affected the clinical outcomes.

While surgery led to a significant improvement of nerve root compression signs, patient satisfaction was impaired by symptoms which were due to the collateral damage the surgeon had produced. Interestingly this fear is still immanent in today's public opinion about disc surgery.

The reduction of collateral damage was the driving force for the two pioneers of lumbar microsurgery. In the same year 1977 Yasargil and Caspar described independently a microsurgical interlaminar approach [12, 13], Figures 6(a) and 6(b). One year later, it was "Tex" Williams who was the first surgeon to perform this approach in the US [14]. The pioneering work of JA McCulloch made this approach popular in the 90s of the last century and it has become a "gold standard" at least in the neurosurgical community worldwide [15]. Other approaches such as the lateral extraforaminal access have been described in this book as well.

"Microendoscopic discectomy" was described in the beginning of this century as a modification of the microsurgical technique where the surgical microscope is replaced by "open" endoscopy [16]. This technique however did not add any further technical or clinical advantages. However both minimally invasive techniques are practiced with good and reproducible clinical outcomes [17].

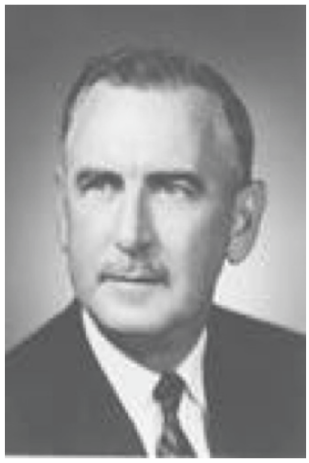
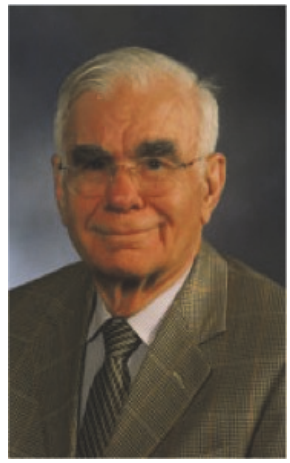


Figure 5: JG Love: first description of interlaminar approach, 1939.



(a)

(b)

Figure 6: (a) G Yasargil, (b) W Caspar: first description of microsurgical interlaminar approach.

*2.2. Lessons Learnt from Microsurgical Techniques.* In summary lumbar microsurgery has significantly improved clinical short-term outcomes of lumbar discectomy mainly by reducing iatrogenic collateral damage. Thus, hospitalization times have become shorter, postop pain levels are lower, and intraoperative blood loss as well as the risk of infection is less.

Even though the advantages are obvious, several lessons had to be learnt by the protagonists of such techniques.

Since there is obviously no effect on the long-term outcome of lumbar discectomy, the acceptance especially by the older generation of spine surgeons has been low despite the obvious advantages.

It has been known for many years that long-term outcome of lumbar discectomy has different predictors than the short-term outcome [18]. This is due to the fact that there is a progressive degeneration of the spine which can cause clinical symptoms at other levels which are not related to a previous disc surgery.

However we have learnt that one of the strongest predictors of a good long-term outcome is a good short-term outcome. And we have also learnt that a good short-term outcome is predicted by 2 factors: (1) the efficacy of nerve root compression and (2) the extent of iatrogenic collateral damage to muscles, ligaments, facet joints, nerve, and epidural space.

*2.3. Part 2: The "Parallel World" of "Percutaneous" and Endoscopic Techniques.* It was in 1964 when Lyman Smith published a paper about enzymatic dissolution of the nucleus pulposus, a procedure which he called chemonucleolysis [19]. It was known at that time that an enzyme called Chymopapain, which was derived from the papaya plant, was able to hydrolyze proteoglycans. During experimental work in the 50s of the last century about the effects of papain, there was an interesting incidental finding. Intravenous injection of papain in rabbits resulted in a reversible collapse of rabbit ears [20], a finding which suggested an effect of this enzyme on cartilage. Similar effects were then reported on cartilage of joints, trachea, larynx, and bronchi. Since further studies on rabbits had shown that this enzyme dissolves the nucleus pulposus [21], it was Lyman Smith's idea that an application in contained disc herniations could lead to an "intradiscal decompression", thus relieving the symptoms from nerve compression due to a bulging lumbar disc.

In the 1980s this procedure became popular as the least invasive technique to treat herniated lumbar discs.

Mid- to long-term outcomes were good, complications were rare, and chemonucleolysis seemed to become a viable alternative to surgical discectomy [22, 23].

Then something happened which was more a psychological phenomenon than rational based medical evolution. In the 70s, Hijikata, a Japanese surgeon, was fascinated by the posterolateral access to the disc space which was, at that time, in the pre-CT and pre-MRI era, very popular to perform diagnostic discographies (Figure 7). He developed tubes through which he could introduce this approach down to the posterolateral annulus under fluoroscopic control. With special trephines he could perforate the annulus and, using pituitary rongeurs, he could perform what he called

Figure 7: Hijikata: first percutaneous nucleotomy, 1975.

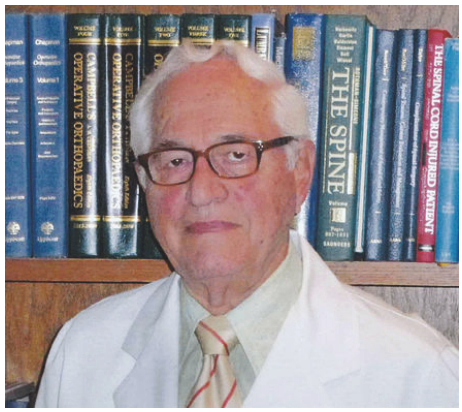



Figure 8: P Kambin: percutaneous discectomy, 1986.

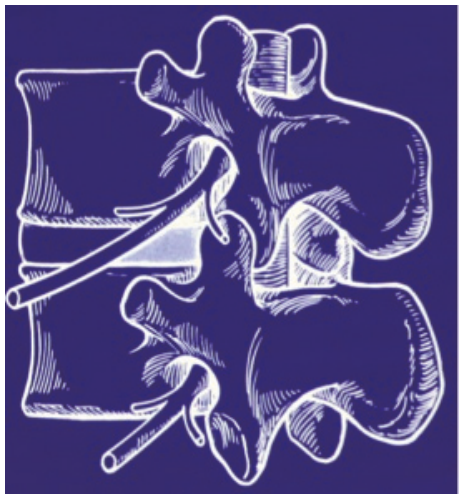


Figure 9: Kambin's triangle for a safe posterolateral approach.

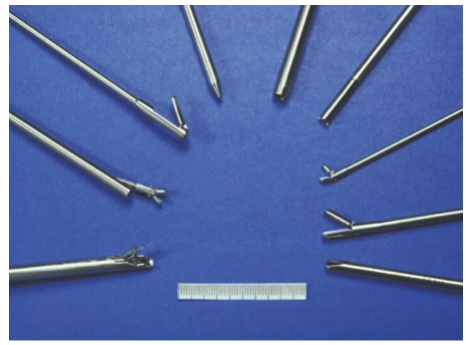


Figure 10: Early Instrument set for percutaneous endoscopic discectomy.

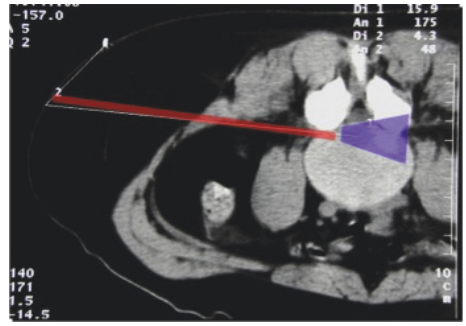


Figure 11: Approach corridor and visual field for transforaminal approach.

"percutaneous nucleotomy". He published this procedure in a regional scientific journal in Japanese language [24]. This was one of the reasons why this procedure did not gain widespread attention among the surgical community but it was the birth of "percutaneous" and, later, endoscopic discectomy.

It was the great merit of Parviz Kambin a Philadelphian spine surgeon to further develop this procedure in the 1980s [25–28] (Figure 8).

It is the "Kambin triangle" (the safe corridor to the lumbar disc between the exiting nerve root and the superior facet) which reminds us of his pioneering work (Figure 9).

Schreiber, Suezawa, and Leu were the first to have the idea to perform this percutaneous nucleotomy under visual control using and endoscope (discoscopy) [29].

The author of this review adopted this technique, refined the instrument set [30] (Figure 10), and published the results of a randomized controlled trial comparing microdiscectomy with endoscopic posterolateral discectomy [31].

A more lateral access route was described by Hal Mathews and Tony Yeung in the second half of the 1990s [32–34].

This lateral extraforaminal approach enabled the removal of far lateral disc herniations as well as more medially located pathologies because the approach corridor was more parallel to the posterior rim of the annulus (Figure 11).

*2.4. Lessons Learnt.* The indication spectrum for posterolateral and transforaminal endoscopic techniques was limited,

Figure 12: A Yeung: first application of transforaminal approach under continuous irrigation.

Figure 13: S Rütten: first interlaminar approach and application of arthroscopic technique.

which was one of the reasons why endoscopic discectomy remained at a low level of acceptance among spine surgeons in the 1980s and 1990s.

There were other reasons: the variety of instruments was limited, the optical systems were not as good as nowadays, and the technical advantages as compared to microsurgery were small.

*2.5. Part 3: From a Nondisruptive to a Disruptive Surgical Technology.* But what was the missing link or major step? The answer is simple: endoscopy was used in a "dry" environment because the technical advantages of joint arthroscopy were not applied.

Whereas in joint arthroscopy surgical dissection was performed "under water" with continuous irrigation and suction, this principle was not applied in the spine because of the erroneous assumption that irrigation might not be of help or necessary in non-preformed anatomic spaces. The advantages of continuous irrigation (hemostasis, flushing of small bleeding, identification of the bleeding source, better identification of microanatomy, and separation of tissue layers by simple irrigation) were not realized.

Moreover, the technique focussed on lateral extraforaminal approaches, and the most traditional interlaminar approach was believed not to be feasible with such a technique.

This is why "the first wave" of lumbar endoscopic techniques remained a nondisruptive technology.

Things changed in the late 90s. It was the merit of Anthony Yeung who started to consequently apply arthroscopic technology for transforaminal as well as interlaminar approaches [37, 50, 51] (Figure 12).

There were three major steps, which transferred spinal endoscopy into a disruptive technology:

(1) "under-water-dissection": continuous irrigation reduced intra- and postop bleeding and infection rates and significantly improved visibility of anatomic structures;

(2) the range of approaches increased from pure transforaminal or posterolateral to interlaminar because

(3) rongeurs, high-speed drills, and other instruments could be used.

Success rates increased and recurrence rates decreased. Rapidly this technology was adopted mainly in Asian countries.

At the beginning of the 2000s it was Sebastian Rütten, a German spine surgeon, who adopted this technology and applied it for interlaminar endoscopic approaches. This significantly enlarged the indication spectrum of this technology (Figure 13).

The current indication spectrum for thoracic and lumbar applications is wide and covers all types of degenerative (and other) pathologies which have been a domain of microsurgical techniques in the past (Table 1)

## 3. Summary

The first attempts of endoscopic lumbar spine surgery date back to the early 1980s. However, only in the last decade this technology has become a disruptive technology with the potential to replace microsurgical techniques especially for degenerative lumbar spine disorders.

The strong input and high acceptance among Asian spine surgeons have triggered a very dynamic clinical and scientific workflow on this topic. A PubMed search for scientific publications on endoscopic lumbar spine surgery shows that more than 80% of the publications have their origin in Asian countries. It has been shown that even though there is a certain learning curve for endoscopic techniques, once the surgeon is familiar with it, he can achieve comparable and sometimes better clinical results as conventional microsurgical operations [52–54].

The complication rates of experienced and well-trained surgeons are low [55].

The iatrogenic collateral damage of the different approaches to the lumbar spine is diminished and most of the procedures can be performed in an outpatient setting [56].

*3.1. The Future.* Today we are in a stage which I would call "microendoscopic blending" where the dynamics of technical improvement of endoscopic techniques suggests that the overlap of indications for this technology vs. microsurgery

Table 1: Indications for full-endoscopic posterior/lateral thoracic and lumbar spine surgery.

| |
|---|
| (i) Decompression of central and foraminal spinal stenosis [35, 36] |
| (ii) Decompression of lateral recess stenosis [37] |
| (iii) Removal of all types of disc herniations incl. difficult cases and recurrent disc herniations [38] |
| (a) Medial disc herniations [39, 40] |
| (b) Down migrated disc herniations [41] |
| (c) Bilateral disc herniations [42] |
| (d) Recurrent disc herniations [43] |
| (e) Calcified disc herniations [44] |
| (iv) Removal of synovial cysts [45] |
| (v) Removal of epidural hematoma [46] |
| (vi) Removal of thoracic disc herniations and decompression of thoracic stenosis [47, 48] |
| (vii) Palliative decompression metastases [49] |

will step by step convert into a scenario where endoscopic techniques replace microsurgical techniques. The great challenge is the learning curve and the training of young surgeons. The acceptance of this technology is high among young surgeons but it is the task and duty of the protagonists of the older generation, the hospitals, and the scientific societies to develop learning- and training-concepts to shorten learning curves and to improve technical quality and clinical outcomes.

## Conflicts of Interest

Concerning this manuscript I declare that I have no conflicts of interest to disclose.

## References


[1] R. B. Cloward, "The treatment of ruptured lumbar intervertebral discs by vertebral body fusion. I. Indications, operative technique, after care," *Journal of Neurosurgery*, vol. 10, no. 2, pp. 154–168, 1953.

[2] G. W. Smith and R. A. Robinson, "The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion," *The Journal of Bone & Joint Surgery*, vol. 40, no. 3, pp. 607–624, 1958.

[3] I. Omeis, J. A. DeMattia, V. H. Hillard, R. Murali, and K. Das, "History of instrumentation for stabilization of the subaxial cervical spine," *Neurosurgical Focus*, vol. 16, no. 1, article no. E10, 2004.

[4] J. Böhler and T. Gaudernak, "Anterior plate stabilization for fracture-dislocations of the lower cervical spine," *Journal of Trauma - Injury Infection and Critical Care*, vol. 20, no. 3, pp. 203–205, 1980.

[5] W. Caspar, D. D. Barbier, and P. M. Klara, "Anterior cervical fusion and caspar plate stabilization for cervical trauma," *Neurosurgery*, vol. 25, no. 4, pp. 491–502, 1989.

[6] H. Oppenheim and F. Krause, "Ueber Einklemmung bzw. Strangulation der Cauda equina," *Deutsche Medizinische Wochenschrift*, vol. 35, no. 16, pp. 697–700, 1909.

[7] J. E. Goldthwait, "The lumbosacral articulation: an explanation of many cases of lumbago, sciatica and paraplegia," *The New England Journal of Medicine*, vol. 164, no. 11, pp. 365–372, 1911.

[8] G. S. Middleton and J. H. Teacher, "Injury of the spinal cord due to rupture of the intervertebral disc during muscular effort," *Glasgow Medical Journal*, vol. 76, pp. 1–6, 1911.

[9] A. W. Adson and W. O. Ott, "Results of the removal of tumors of the spinal cord," *Archives of Neurology & Psychiatry*, vol. 8, no. 5, pp. 520–537, 1922.

[10] W. J. Mixter and J. S. Barr, "Rupture of the intervertebral disc with involvement of the spinal canal," *The New England Journal of Medicine*, vol. 211, no. 5, pp. 210–214, 1934.

[11] J. G. Love, "Removal of the protruded interlaminar discs without laminectomy," *Mayo Clinic Proceedings*, vol. 14, article no. 800, 1939.

[12] M. G. Yasargil, "Microsurgical operation of herniated lumbar disc," in *Lumbar Disc Adult Hydrocephalus*, vol. 4 of *Advances in Neurosurgery*, pp. 81-81, Springer, Berlin, Heidelberg, Germany, 1977.

[13] W. Caspar, "A new surgical procedure for lumbar disc herniation causing less tissue damage through a microsurgical approach," in *Lumbar Disc Adult Hydrocephalus*, vol. 4 of *Advances in Neurosurgery*, pp. 74–80, Springer, Berlin, Heidelberg, Germany, 1977.

[14] R. W. Williams, "Microlumbar discectomy. A conservative surgical approach to the virgin herniated lumbar disc," *The Spine Journal*, vol. 3, no. 2, pp. 175–182, 1978.

[15] J. A. McCulloch and P. H. Young, Eds., *Essentials of Spinal Microsurgery*, Lippincott Raven, 1998.

[16] M. J. Perez-Cruet, K. T. Foley, R. E. Isaacs et al., "Microendoscopic lumbar discectomy: technical note," *Neurosurgery*, vol. 51, no. 5, pp. S129–S136, 2002.

[17] M. R. Rasouli, V. Rahimi-Movaghar, F. Shokraneh, M. Moradi-Lakeh, and R. Chou, "Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation," *Cochrane Database of Systematic Reviews*, vol. 9, Article ID CD010328, 2014.

[18] P. J. Lewis, B. K. Weir, R. W. Broad, and M. G. Grace, "Long-term prospective study of lumbosacral discectomy," *Journal of Neurosurgery*, vol. 67, no. 1, pp. 49–53, 1987.

[19] L. Smith, "Enzyme dissolution of the nucleus pulposus in humans," *The Journal of the American Medical Association*, vol. 187, no. 2, pp. 137–140, 1964.

[20] L. Thomas, "Reversible collapse of rabbit ears after intravenous papain, and prevention of recovery by cortisone," *The Journal of Experimental Medicine*, vol. 104, no. 2, pp. 245–252, 1956.

[21] E. C. Saunders, "Treatment of the canine intervertebral disc syndrome with chymopapain," *Journal of the American Veterinary Medical Association*, vol. 1, no. 145, pp. 893–896, 1964.

[22] F. Mansfield, K. Polivy, R. Boyd, and J. Huddleston, "Long-term results of chymopapain injections," *Clinical Orthopaedics and Related Research*, no. 206, pp. 67–69, 1986.

[23] N. Flanagan and L. Smith, "Clinical studies of chemonucleolysis patients with ten- to twenty-year follow-up evaluation," *Clinical Orthopaedics and Related Research*, no. 206, pp. 15–17, 1986.

[24] S. Hijikata, "A method of percutaneous nuclear extraction," *Journal of Toden Hospital*, vol. 5, pp. 39–42, 1975.

[25] P. Kambin and S. Sampson, "Posterolateral percutaneous suction-excision of herniated lumbar intervertebral discs. Report of interim results," *Clinical Orthopaedics and Related Research*, vol. 207, pp. 37–43, 1986.

[26] P. Kambin and M. D. Bracer, "Percutaneous posterolateral discectomy. Anatomy and mechanism," *Clinical Orthopaedics and Related Research*, no. 223, pp. 145–154, 1987.

[27] P. Kambin, J. E. Nixon, A. Chait, and J. L. Schaffer, "Annular protrusion: pathophysiology and roentgenographic appearance," *The Spine Journal*, vol. 13, no. 6, pp. 671–675, 1988.

[28] P. Kambin and J. L. Schaffer, "Percutaneous lumbar discectomy. Review of 100 patients and current practice," *Clinical Orthopaedics and Related Research*, no. 238, pp. 24–34, 1989.

[29] A. Schreiber, Y. Suezawa, and H. Leu, "Does percutaneous nucleotomy with discoscopy replace conventional discectomy? Eight years of experience and results in treatment of herniated lumbar disc," *Clinical Orthopaedics and Related Research*, no. 238, pp. 35–42, 1989.

[30] H. M. Mayer and M. Brock, "Percutaneous lumbar discectomy – The Berlin technique," in *Percutaneous lumbar Discectomy*, H. M. Mayer and M. Brock, Eds., pp. 107–117, Springer, Berlin, Heidelberg, Germany, 1989.

[31] H. M. Mayer and M. Brock, "Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy," *Journal of Neurosurgery*, vol. 78, no. 2, pp. 216–225, 1993.

[32] H. H. Mathews, "Transforaminal microdiscectomy," *Neurosurgery Clinics of North America*, vol. 7, no. 1, pp. 59–63, 1996.

[33] P. M. Tsou and A. T. Yeung, "Transforaminal endoscopic decompression for radiculopathy secondary to intracanal noncontained lumbar disc herniations: outcome and technique," *The Spine Journal*, vol. 2, no. 1, pp. 41–48, 2002.

[34] A. T. Yeung and C. A. Yeung, "Advances in endoscopic disc and spine surgery: foraminal approach," *Surgical Technology International*, vol. 11, pp. 255–263, 2003.

[35] M. Komp, P. Hahn, H. Merk, G. Godolias, and S. Ruetten, "Bilateral operation of lumbar degenerative central spinal stenosis in full-endoscopic interlaminar technique with unilateral approach: Prospective 2-year results of 74 patients," *Journal of Spinal Disorders & Techniques*, vol. 24, no. 5, pp. 281–287, 2011.

[36] C. Lee, M. Choi, D. S. Ryu et al., "Efficacy and safety of full-endoscopic decompression via interlaminar approach for central or lateral recess spinal stenosis of the lumbar spine: a meta-analysis," *The Spine Journal*, vol. 43, no. 24, pp. 1756–1764, 2018.

[37] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: a prospective, randomized, controlled study," *Journal of Neurosurgery: Spine*, vol. 10, no. 5, pp. 476–485, 2009.

[38] H. S. Kim, B. Paudel, J. S. Jang, K. Lee, S. H. Oh, and I. T. Jang, "Percutaneous endoscopic lumbar discectomy for all types of lumbar disc herniations (LDH) including severely difficult and extremely difficult LDH cases," *Pain Physician*, vol. 21, no. 4, pp. E401–E408, 2018.

[39] C. Shi, W. Kong, W. Liao et al., "The early clinical outcomes of a percutaneous full-endoscopic interlaminar approach via a surrounding nerve root discectomy operative route for the treatment of ventral-type lumbar disc herniation," *BioMed Research International*, vol. 2018, Article ID 9157089, 6 pages, 2018.

[40] C. Ma, G. Liu, L. Xie et al., "Full-endoscopic interlaminar approach discectomy for central lumbar disc extrusion," *National Medical Journal of China*, vol. 95, no. 23, pp. 1807–1810, 2015.

[41] Y. Inomata, Y. Oshima, H. Inoue, Y. Takano, H. Inanami, and H. Koga, "Percutaneous endoscopic lumbar discectomy via adjacent interlaminar space for highly down-migrated lumbar disc herniation: a technical report," *Journal of Spine Surgery*, vol. 4, no. 2, pp. 483–489, 2018.

[42] S. Choi, N. Adsul, H. Kim et al., "Percutaneous endoscopic interlaminar unilateral ventral dural approach for symptomatic bilateral L5-S1 herniated nucleus pulposus: technical note," *Journal of Neurological Surgery Part A: Central European Neurosurgery*, vol. 79, no. 06, pp. 518–523, 2018.

[43] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Recurrent lumbar disc herniation after conventional discectomy: a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision," *Journal of Spinal Disorders & Techniques*, vol. 22, no. 2, pp. 122–129, 2009.

[44] H. S. Kim, N. Adsul, Y. S. Ju et al., "Full endoscopic lumbar discectomy using the calcification floating technique for symptomatic partially calcified lumbar herniated nucleus pulposus," *World Neurosurgery*, vol. 119, pp. 500–505, 2018.

[45] M. Komp, P. Hahn, S. Ozdemir et al., "Operation of lumbar zygoapophyseal joint cysts using a full-endoscopic interlaminar and transforaminal approach," *Surgical Innovation*, vol. 21, no. 6, pp. 605–614, 2014.

[46] Y. Cheng, K. Lee, P. Lin et al., "Full-endoscopic interlaminar removal of chronic lumbar epidural hematoma after spinal manipulation," *Surgical Neurology International*, vol. 5, no. 1, p. 55, 2014.

[47] S. Ruetten, P. Hahn, S. Oezdemir et al., "Full-endoscopic uniportal decompression in disc herniations and stenosis of the thoracic spine using the interlaminar, extraforaminal, or transthoracic retropleural approach," *Journal of Neurosurgery: Spine*, vol. 29, no. 2, pp. 157–168, 2018.

[48] S. Ruetten, P. Hahn, S. Oezdemir, X. Baraliakos, G. Godolias, and M. Komp, "Operation of soft or calcified thoracic disc herniations in the full-endoscopic uniportal extraforaminal technique," *Pain Physician*, vol. 21, no. 4, pp. E331–E340, 2018.

[49] S. Tsai, H. Wu, C. Cheng, and C. Chen, "Full endoscopic interlaminar approach for nerve root decompression of sacral metastatic tumor," *World Neurosurgery*, vol. 112, pp. 57–63, 2018.

[50] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach," *Journal of Neurosurgery: Spine*, vol. 6, no. 6, pp. 521–530, 2007.

[51] S. Ruetten, M. Komp, and G. Godolias, "A new full-endoscopic technique for the interlaminar operation of lumbar disc herniations using 6-mm endoscopes: prospective 2-year results of 331 patients," *Minimally Invasive Neurosurgery*, vol. 49, no. 2, pp. 80–87, 2006.

[52] B. Wang, G. Lü, A. A. Patel, P. Ren, and I. Cheng, "An evaluation of the learning curve for a complex surgical technique: the full endoscopic interlaminar approach for lumbar disc herniations," *The Spine Journal*, vol. 11, no. 2, pp. 122–130, 2011.

[53] H.-T. Hsu, S.-J. Chang, S. S. Yang, and C. L. Chai, "Learning curve of full-endoscopic lumbar discectomy," *European Spine Journal*, vol. 22, no. 4, pp. 727–733, 2013.

[54] H. Xu, X. Liu, G. Liu, J. Zhao, Q. Fu, and B. Xu, "Learning curve of full-endoscopic technique through interlaminar approach for L5/S1 disk herniations," *Cell Biochemistry and Biophysics*, vol. 70, no. 2, pp. 1069–1074, 2014.

[55] T.-H. Xie, J.-C. Zeng, Z.-H. Li et al., "Complications of lumbar disc herniation following full-endoscopic interlaminar lumbar discectomy: A large, single-center, retrospective study," *Pain Physician*, vol. 20, no. 3, pp. E379–E387, 2017.

[56] S. Kamson, A. Trescot, P. D. Sampson, and Y. Zhang, "Full-endoscopic assisted lumbar decompressive surgery performed in an outpatient, ambulatory facility: Report of 5 years of complications and risk factors," *Pain Physician*, vol. 20, no. 2, pp. E221–E231, 2017.

Hindawi
BioMed Research International
Volume 2019, Article ID 6078469, 11 pages
https://doi.org/10.1155/2019/6078469

*Research Article*

# Comparative Analysis between Three Different Lumbar Decompression Techniques (Microscopic, Tubular, and Endoscopic) in Lumbar Canal and Lateral Recess Stenosis: Preliminary Report

**Chul-Woo Lee, Kang-Jun Yoon, and Sang-Soo Ha**

*Department of Neurosurgery, St. Peter's Hospital, Seoul 135-809, Republic of Korea*

Correspondence should be addressed to Chul-Woo Lee; mannitol240@gmail.com

Received 14 September 2018; Accepted 7 March 2019; Published 24 March 2019

Guest Editor: Yue Zhou



*Purpose.* The purpose of our study is to compare the results of spinal decompression using the full-endoscopic interlaminar technique, tubular retractor, and a conventional microsurgical laminotomy technique and evaluate the advantages and clinical feasibility of minimally invasive spinal (MIS) lumbar decompression technique in the lumbar canal and lateral recess stenosis. *Methods.* The authors retrospectively reviewed clinical and radiological data from 270 patients who received microsurgical (group E: 72 patients), tubular (group T: 34 patients), or full-endoscopic decompression surgery (group E: 164 patients) for their lumbar canal and lateral recess stenosis from June 2016 to August 2017. Clinical (VAS, ODI, and Mcnab criteria), radiologic (spinal canal diameter, segmental dynamic angle, and disc height), and surgical outcome parameters (CPK level, Operative time, blood loss, and hospital stay) were evaluated pre- and postoperatively and compared among the three groups by means of statistical analysis. Failed cases and complications were reviewed in all groups. *Results.* The mean follow-up period was 6.38 months. The Overall clinical success rate was 89.4%. All groups showed favorable clinical outcome. The clinical and radiologic results were similar in all groups. Regarding surgical outcome, group E showed longer operation time than group M and T (group E: 84.17 minutes/level, group M: 52.22 minutes/level, and group T: 66.12 minutes/level) ($p<0.05$). However, groups E and T showed minimal surgical invasiveness compared with group M. Groups E and T showed less immediate postoperative back pain (VAS) (group E: 3.13, group M: 4.28, group T: 3.54) ($p<0.05$), less increase of serum CPK enzyme (group E: 66.38 IU/L, group M: 120 IU/L, and group T: 137.5 IU/L) ($p<0.05$), and shorter hospital stay (group E: 2.12 days, group M: 4.85 days, and group T: 2.83 days) ($p<0.05$). The rates of complications and revisions were not significantly different among the three groups. *Conclusions.* MIS decompression technique is clinically feasible and safe to treat the lumbar canal and lateral recess stenosis, and it has many surgical advantages such as less muscle trauma, minimal postoperative back pain, and fast recovery of the patient compared to traditional open microscopic technique.

## 1. Introduction

Traditional treatment of spinal stenosis has been wide laminectomy involving undercutting of the medial facet and foraminotomy [1]. With the introduction of the operating microscope, laminectomy was refined, widely accepted by spine surgeons. More limited decompressive procedures including bilateral foraminotomies and unilateral approaches to bilateral decompression have been shown to be effective [2–4]. Nonetheless, tissue-sparing procedures are becoming more common. Among those MIS decompression techniques for the lumbar canal and lateral recess stenosis, techniques by using tubular retractor and percutaneous endoscope have been reported to have many surgical advantages such as less postoperative back pain and benefits for rehabilitation [3, 5–12]. However, its clinical efficacy and safety were not proved to the extent to satisfy most spine surgeons. The present study was undertaken to retrospectively compare the results of spinal decompression using the full-endoscopic interlaminar technique (group E), tubular retractor (group T), and a conventional microsurgical laminotomy technique (group M) with a goal to evaluate the advantages and clinical

Table 1: Patient demographics and characteristics.

| | Endoscopic | Tubular | Microscopic | *p* value |
|---|---|---|---|---|
| Number of patients (N=270) | 164 | 34 | 72 | |
| Levels (N=315)<br>(1 level/ 2 level/ 3 level) | 188<br>(144/16/4) | 40<br>(28/6/0) | 87<br>(60/9/3) | |
| Average Age (years) | 53.22±3.5 | 61.80±7.81 | 59.32±8.28 | NS |
| Gender (male/female) | 52/112 | 10/24 | 21/51 | NS |
| BMI | 28.1±3.4 | 27.4±3.5 | 23.2±3.7 | NS |
| Preoperative VAS(back pain) | 5.97±2.77 | 6.61±2.46 | 5.09±2.84 | NS |
| Preoperative VAS(Leg pain) | 7.01± 2.31 | 7.38±2.40 | 6.47±2.73 | NS |
| Preoperative ODI | 69.8±5.4 | 68.6±5.8 | 56..3±6.1 | NS |
| Spinal canal dimension ($mm^2$) | 81.67±31.30 | 89.07±40.16 | 93.52±44.80 | NS |
| Mean follow up duration (months) | 6.42±2.68 | 6.21±3.54 | 6.32±4.82 | NS |
| Preoperative serum CPK (IU/L) | 109.73±46.21 | 107.2±53.11 | 99.11±46.44 | NS |

NS=not significant; BMI= Body Mass Index; VAS=Visual Analogue Scale; ODI=Oswestry Disability Index; CPK=creatine phosphokinase.

feasibility of MIS lumbar decompression technique in lumbar central spinal stenosis. To the best of our knowledge, this is the first comparative study to analyze the three methods (endoscopic, tubular, and microscopic) and give the answer to the question what the advantages of MIS decompression technique compared to previous open laminectomy are in the treatment of lumbar canal and lateral recess stenosis.

## 2. Materials and Methods

This study was approved by the relevant institutional review board.

*2.1. Patient Population.* 277 patients were enrolled by inclusion and exclusion criteria. Seven patients (group E: five patients, group M: two patients) were dropped out due to several reasons (reluctant to further visit to out patient clinic, cannot touch by call). A retrospective review was performed on 270 patients (187f, 83m) who had undergone full-endoscopic (164 patients), tubular (34 patients), and microscopic (72 patients) laminotomy and flavectomy, for degenerative lumbar central or lateral recess stenosis between June 2016 and August 2017 at a single center. Inclusion criteria were patients who were preoperatively diagnosed with lumbar central canal or lateral recess stenosis with the symptoms of neurogenic intermittent claudication (NIC) and radiculopathy and refractory to conservative treatment at least for three months. Segmental instability, degenerative spondylolisthesis more than Meyerding Grade I, multidirectional rotation slide, and Scoliosis more than 20 degrees, combined foraminal stenosis in the same or lower level or coexisting pathologic conditions such as acute inflammation, infection, or tumor, were excluded. There were no significant differences in preoperative data between different three groups except the total number of patients according to the technique. Patient's demographics and characteristics are summarized (Table 1).

*2.2. The Methods of the Technique Selection.* Three spine surgeons (CW Lee, SS Ha, KJ Yoon) in single center performed the surgeries which were recruited in this study. Each of three surgeons selected the single decompressive method which was the best at their own hands for all their patients (CW Lee: endoscopic surgery, SS Ha: Tubular surgery, and KJ Yoon: microscopic surgery). All three surgeons who performed surgeries in this study had already a great deal of traditional spinal surgery experience (over 5000 cases). But, there was some difference in the number of each of the cases which each surgeon had experienced before the study (CW Lee: 42 endoscopic lumbar decompressive surgery cases, SS Ha: 612 tubular lumbar decompressive surgery cases, and KJ Yoon: 1235 microscopic lumbar decompressive surgery cases).

*2.3. Surgical Technique.* General operative descriptions are given below for each type of procedure. All the patients underwent general or epidural anesthesia with sedation. The patients were placed in a prone position with positioning pads under the shoulders and superior iliac crests. The affected level was verified by intraoperative C-arm fluoroscopy. The operation was performed bilaterally via a unilateral access using an "undercutting technique."

*2.3.1. Endoscopic Decompression.* Percutaneous endoscopic laminotomy with flavectomy by uniportal, unilateral Approach for the lumbar canal or lateral recess stenosis was previously introduced by authors [13]. Endoscopic: The operative procedure was performed by using a complete endoscopic instrument system: Ilessys Delta® (joimax GmbH, Raumfabrik 33A, Amalienbadstraße, 76227 Karlsruhe, Germany) or Vertebris stenosis (Richard Wolf GmbH, Knittlingen, Germany). After a paramedian skin incision approximately 9 mm long which targets the caudal margin of the upper lamina, blunt insertion of a serial dilator was followed. The operation sheath over the dilatator was inserted with the beveled opening directed medially toward the ligamentum

Table 2: The Comparison between 3 different decompressive techniques.

| | Endoscopic (N=164) | Tubular (N=34) | Microscopic (N=72) |
|---|---|---|---|
| Anesthesia | Epidural (N=52) or General (N=112) | Epidural | Epidural |
| Skin incision (mm) | 10 | 16-18 | 25-35 |
| Retractor for working space | Ø 10mm Cannula | Ø 1.6~1.8mm Tube | Taylor retractor |
| Operative instruments | Ø 3.5, 4.5mm burr Endoscopic Kerrison punch (3, 4, 5 mm) | Ø 5, 6mm burr Kerrison punch (3,5 mm) | |
| Hemostasis | Radiofrequency, Irrigative pressure | Bipolar, Suction | |

flavum. Under the endoscopic direct visual control, ipsilateral decompression was performed first by means of craniocaudal laminotomy and partial facetectomy with endoscopic drills and punches. The contralateral side was entered dorsally to the dura. The ligamentum flavum was initially left intact as a protective barrier for the dura and neural components. Contralateral bony structure including partial lamina and facet was decompressed. Subsequently, ligamentum flavum was removed in en bloc fashion. The decompression was finished when the decompressed dura and spinal nerves were clearly seen on both sides. On a case by case basis, disc herniation to compress the neural structures was removed. The incision was sutured in a subcutaneous layer with Vicryl followed by Dermabond on the skin edge.

*2.3.2. Tubular Decompression.* The tubular decompression for spinal canal and bilateral lateral recess stenosis with unilateral approach is described in detail elsewhere [14]. An 18 mm paramedian horizontal skin incision was then made. The muscle was sequentially dilated, after which we placed an 18 mm working channel of the shortest length that would allow the adequate depth of access (usually 50 or 60 mm). The operative microscope was moved into the field, and the laminar edge was identified. A laminotomy was performed, extending cephalad above the insertion of the ligamentum flavum on the inferior surface of the superior lamina (to ensure adequate resection of ligamentous compressive elements) and caudally to include a smaller portion of the superior aspect of the inferior lamina exposing the pedicle. Resection of the medial facet complex was performed as it is necessary to decompress the lateral recess and the foramina adequately. The working channel was then angled medially to expose the anterior aspect of the spinous process, which was then removed utilizing a drill. This procedure exposed the lateral recess on the contralateral side where the residual lamina and ligamentum flavum could be resected using the drill, Kerrison punches, and curettes. The angle of approach is the same as that commonly taken during an open laminectomy that allows undermining of the contralateral facets, making the anatomy familiar to most spine surgeons. Satisfactory decompression of the lateral recess and foramina is achieved under direct visualization. The incision was closed in layers with Vicryl followed by Steristrips.

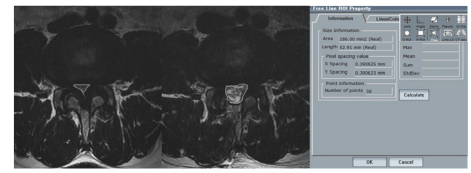


Figure 1: MRIs showing pre- and postoperative change of dural sac cross sectional area using an automated and digitalized tool in the PACS system.

*2.3.3. Microscopic Decompression.* The microsurgical procedure of unilateral approach with bilateral decompression (ULBD) is described in detail elsewhere [6, 15]. Surgery was performed in a standardized manner with a minimally invasive approach via a unilateral laminotomy with partial resection of the inferior aspect of the cranial hemilamina and, usually to a minimal degree, from the superior aspect of the caudal hemilamina. After the ipsilateral decompression, the base of the spinous process was undercut by medial angulation of the operative microscope, and the contralateral hemilamina together with the hypertrophied medial facet was partially removed after bilateral flavectomy, and the lateral recess and neural foramina were decompressed contralaterally. Care was taken not to detach the spinous process completely and to preserve the hypertrophied ligamentum flavum as long as possible for the protection of the dural sac and nerve root during drilling.

The difference of 3 decompression techniques was summarized and compared (Table 2).

*2.4. Radiographic Analysis.* Radiologic measurements were done using automated and digitalized tools in the PACS system, PiView 1.0 (Infinitt Co. Ltd., Seoul, Korea). To evaluate the degree of decompression radiologically, the cross-sectional area of dural sac at the disc level was measured for the preoperative and postoperative MRI, by using the digitalized tool (Figure 1). Spinal canal dimension was investigated and compared pre- and postoperatively by axial MRI image at middisc level. All patients underwent functional X-rays both preoperatively and at the end of the follow-up period.

Table 3: The change of spinal canal dimension ($mm^2$).

| | Pre Mean(SD) | Post Mean(SD) | $p$ value |
|---|---|---|---|
| Endoscopic | 81.67±31.30 | 164.30±53.82 | ≤0.001∗ |
| Tubular | 89.07±40.16 | 153.81±67.9 | ≤0.001∗ |
| Microscopic | 93.52±44.80 | 179.16±52.72 | ≤0.001∗ |

∗=statistically significant.

*2.5. Outcome Measures.* Patients were evaluated pre- and postoperatively with the Visual Analog Scale for leg and pain, Oswestry Disability Index scores, and the modified MacNab criteria. Postoperative patient satisfaction survey, which was composed of two questions, was also performed. Serum creatine phosphokinase (CPK) enzyme was measured before the operation and a day after the operation to investigate the degree of iatrogenic muscle injury according to the operative methods. Complications related to the surgery and surgical outcomes such as operative time, hospital stay, and blood loss including postoperative hemovac drainage, were reviewed.

*2.6. Statistical Analysis.* Statistical analysis was conducted using SPSS. All intra- and intergroup comparisons were conducted using a student's t-test, paired t-test, one-way ANOVA, and chi-squared test as appropriate. Statistical significance was accepted at $p<0.05$.The materials and methods section should contain sufficient detail so that all procedures can be repeated. It may be divided into headed subsections if several methods are described.

## 3. Results

*3.1. Clinical and Functional Outcomes.* The average follow-up duration was 6.38±4.35 months. The three groups had comparable VAS and ODI scores preoperatively. At the last postoperative follow-up, similar statistically significant improvements in VAS and ODI outcome scores were found (VAS (back pain-) group E: 5.97-2.35, group T: 6.61-2.28, group M: 5.09-2.83; VAS (leg pain-) group E: 7.01-2.46, group T: 7.48-2.33, group M: 6.47-3.24; ODI-group E: 69.8-46.5, group T: 68.6-34.2, and group M: 56.3-45.3) (Figure 2).

All three groups showed favorable postoperative clinical outcomes. However, VAS score for early postoperative back pain which was evaluated at a day after the operation showed less postoperative back pain in groups E and T compared with group M (group E:3.13, group T: 3.38, and group M: 4.28). The difference between group E and M were statistically significant (p=0.008) (Figure 3).

At the final follow-up review, the modified MacNab criteria were rated as follows: excellent in 142 patients (71.3%) (group E: 92 patients, group T: 20 patients, and group M: 30 patients), good in 99 patients (22.5%) (group E: 53 patients; group T: 11 patients, and group M: 30 patients), fair in 21 patients (4.2%) (group E: 13 patients, group T: 3 patients, and group M: 5 patients), and poor in 5 patients (1.9%) (group E: 3 patients, and group M: 2 patients). Therefore, 93.8% of the all patients answered excellent or good results. Overall success rate was similar among the three groups (group E: 88.4%, group T: 91.1%, and group M: 90.2%) (Figure 4).

From the patient satisfaction survey, 257 patients (95.1%) (group E: 160 patients (97.5%), group T: 31 patients (91.1%), and group M: 66 patients (91.6%)) reported subjective satisfaction and 208 patients (77.0%) (group E: 138 patients (84.1%), group T: 28 patients (82.3%), and group M: 42 patients (59.7%) ) responded that they would recommend this procedure to others. The patients in groups E and T gave more positive responses on the satisfaction survey than group M and the differences in patient responses between groups E and M to both questions and between groups T and M to the second question were statistically significant (Figure 5).

*3.2. Radiological Results.* Dural sac expansion was observed by the comparison of pre- and postoperative MRI axial images. It was statistically significant in all groups. However, our study showed that there was no significant difference among the three groups in the amount of decompression (Table 3). There was no case of postoperative increased kyphosis, instability, and decreased disc height in the operated segment.

*3.3. Surgical Outcomes and Perioperative Complications.* Even though the differences were statistically insignificant, MIS decompression group (groups E and T) showed less blood loss (group E: 35.4 ml, group T: 72 ml, and group M: 134.3 ml). Patients in group E experienced average shorter hospital stays and longer operation times than those in groups T and M (Hospital stay-group E: 2.12 days, group T: 2.83 days, group M: 4.85 days, and p≤0.001; operation time-group E: 84.17 minutes/level, group T: 66.12 minutes/level, group M: 52.22 minutes/level, and p≤0.001).

The results for postoperative changes of serum creatine phosphokinase (CPK) showed that, in general, tubular decompression group had significant increase of serum CPK enzyme compared to endoscopic decompression group (group E: 66.38 IU/L, group T: 137.5 IU/L, group M: 120 IU/L, and p=0.049). Also, endoscopic decompression group showed less increase of CPK enzyme compared to microscopic decompression group, although it was statistically not significant; as the number of decompressed levels increases, such an inclination was more evident (one level-group E: 61.23 IU/L, group T: 132.5 IU/L, and group M: 100.23 IU/L; two levels-group E: 101.23 IU/L, group T: 205.11 IU/L, and group M: 171.81 IU/L; three levels-group E: 111.3 IU/L, and group M: 213.3 IU/L) (Figure 6).

The results showed that there was no significant difference in morbidity rates associated with the procedures (group E,

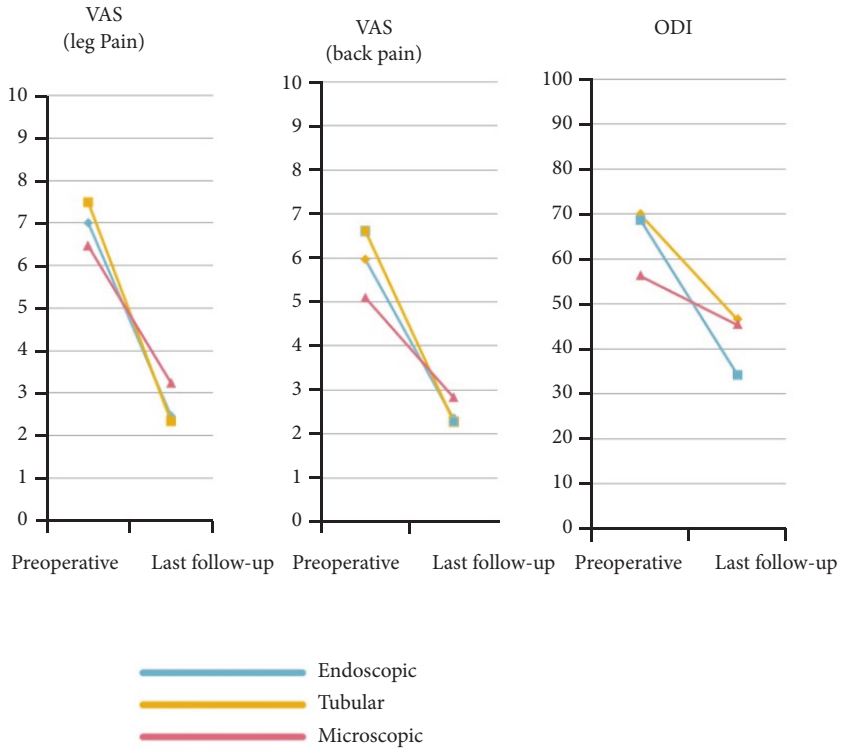



Figure 2: Pre- and postoperative change of VAS and ODI.

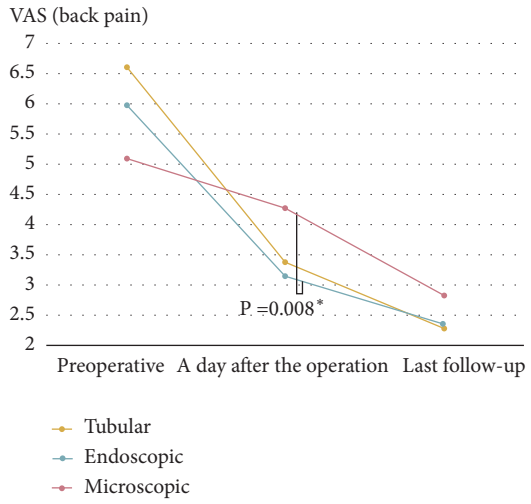



Figure 3: The difference of immediate postoperative back pain. VAS=Visual Analogue Scale and F/U= Follow-up.

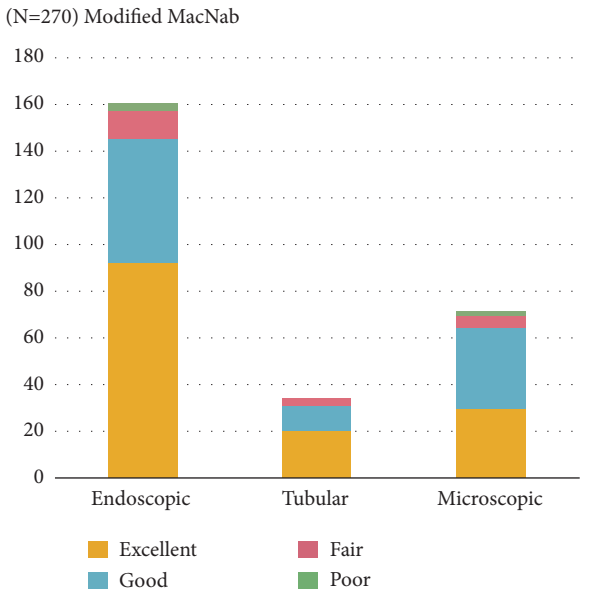



Figure 4: Clinical outcome by modified McNab criteria.

7.9%; group T, 8.8%; group M, 8.3%). Total of 12 patients (group E: seven patients, group T: one patient, and group M: four patients) suffered from postoperative transient dysthesia in the same preoperative dermatomal distribution. Those patients were given selective nerve block and oral gabapentin medication. Their symptoms improved over a 3-month period. There was one case of motor weakness in endoscopic decompression but it recovered to normal status three months later. Five cases of dura tear were reported (group E: four cases, group M: one case). One case of dura tear, which occurred during the microscopic decompressive procedure, was repaired by revision surgery. Four other cases

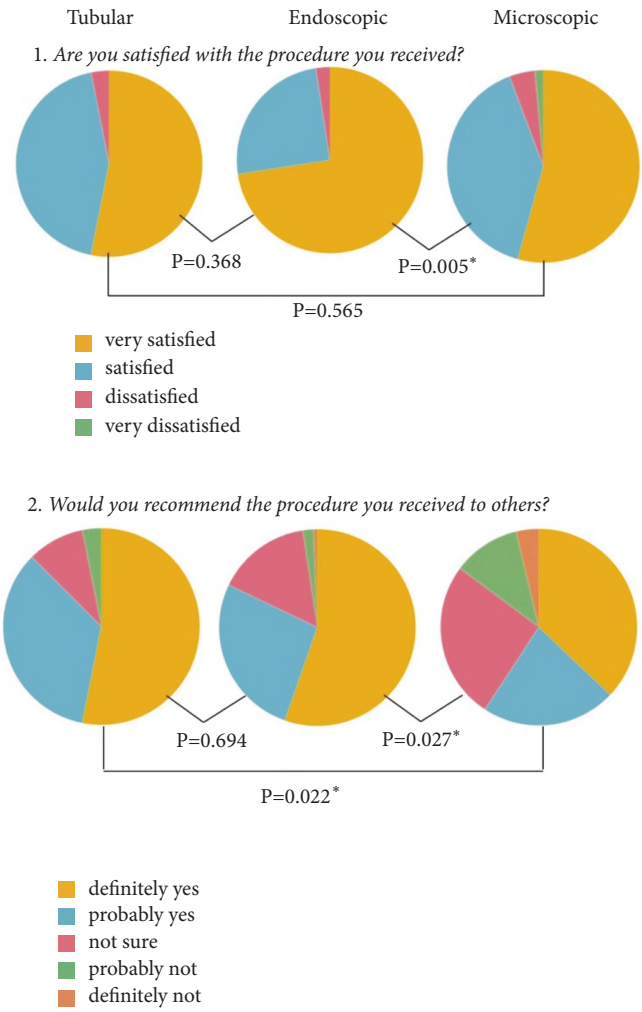



Figure 5: Patient satisfaction.

of dura tear from endoscopic decompressive surgery did not cause further negative consequences and needed secondary repair surgery. Among total cases, there were 7 combined discectomy cases (E group: 3 cases, T group: 2 cases, and M group: 2 cases). Relative high percentage of discectomy cases in tubular decompression group was seen (E: 1.8%, T: 5.8%, and M: 2.7%). It was statistically not significant due to small number of cases. The same revision surgery methods treated two cases of disc reherniation from endoscopic and tubular decompressive surgery. No patient had the revision surgery for the incomplete decompression (Table 4).

## 4. Discussion

Various therapeutic modalities ranging from open laminectomy to minimally invasive decompression were introduced as the surgical treatments of lumbar canal and lateral recess stenosis. Several decompressive techniques have been developed following the MIS concept to minimize iatrogenic injury and preserve segmental stability. Many studies have reported more favorable clinical results with MIS decompressive techniques than traditional methods [3, 5, 6, 16–18]. Today, percutaneous endoscopic spinal surgery has become a standard treatment in various lumbar spinal diseases ranging from a simple contained disc to complicated cases such as highly migrated disc herniation. The spinal stenosis in the canal and foramen can now be operated fully with endoscope [9–11, 19–23]. However, previous studies have also presented that MIS techniques have their own limitations such as stiff learning curves and relatively high complication rates, compared to conventional techniques [5, 12, 24–31]. Some authors have reported successful clinical results of MIS decompressive techniques with the tubular system and full endoscopic system for lumbar stenotic disease [9–11, 29, 32], but apart from these limited studies, there are few reports that explain or convince most spine surgeons of the effectiveness and clinical feasibility of MIS decompressive techniques for the lumbar canal and lateral recess stenosis.

The purpose of this study was to compare the results of spinal decompression using the full-endoscopic interlaminar technique (group E), a tubular retractor (group T) and a

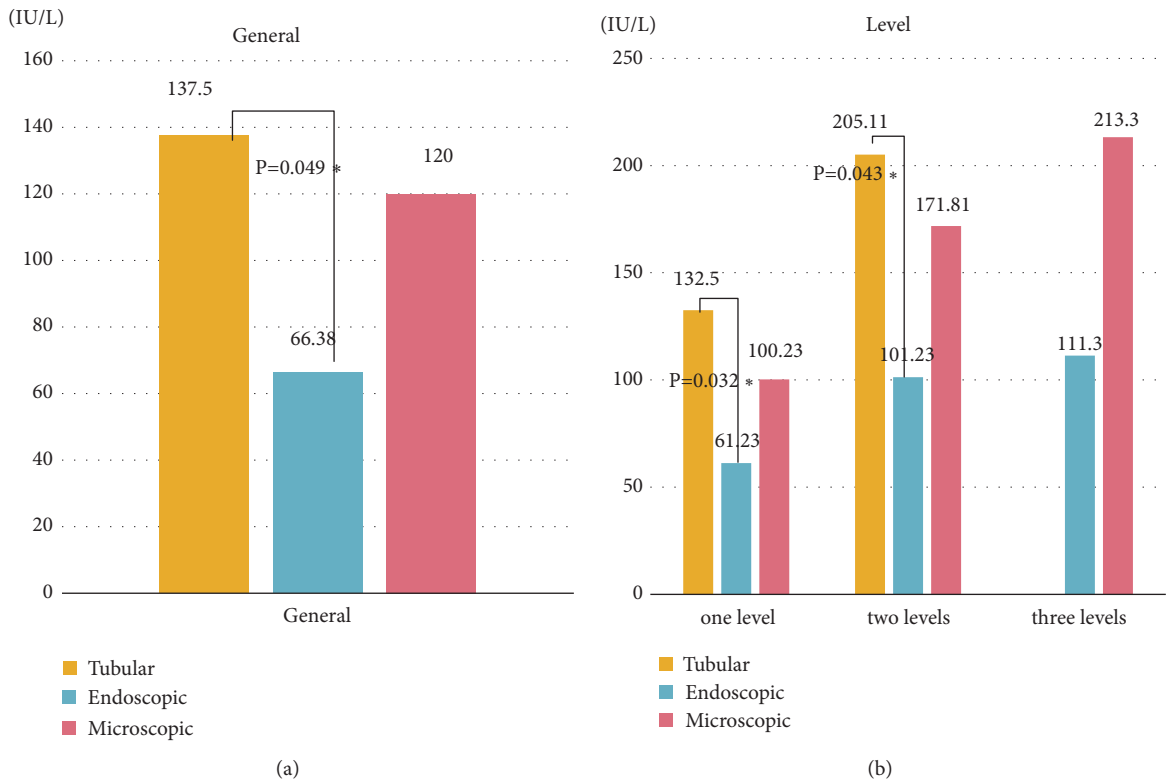



Figure 6: Postoperative increased amount of serum creatine phosphokinase (CPK): (a) comparison between 3 different decompressive methods; (b) comparison between 3 different decompressive methods according to the number of decompressed level.

conventional microsurgical laminotomy technique (group M), and evaluate the advantages and clinical feasibility of MIS lumbar decompression technique in lumbar central spinal stenosis.

*4.1. Clinical Outcome and Patient's Satisfaction.* Several clinical parameters such as VAS and ODI showed significant clinical improvement postoperatively in all groups. These clinical results were similar among the three groups and comparable to those obtained from previously described microsurgical or tubular techniques and corresponded to data reported in the literature [2, 5, 6, 33].

Interestingly, although such clinical parameters showed similar results among the groups at final follow-up, the immediate postoperative results showed that MIS decompression groups induced significantly less back pain compared to the traditional microscopic decompression technique. All patients were treated by same analgesic protocol after the operation regardless of type of the decompressive technique. Only NSAIDs (ibuprofen 400mg, PO, and Bid) were given to the patients 6 hours after the operation until discharge We added other pain killer (piroxicam 20mg, IM, and PRN) if patients complain unbearable postoperative pain during admission (group E: one patient, group T: one patient, and group M: three patients ). But, most patients did not need additional analgesics. We assert that these findings reflect the less tissue damage and minimally invasive nature of the MIS decompression technique, and such a less immediate postoperative back pain was one of the merits of MIS decompression technique.

In this study, another identified advantage of MIS lumbar decompression was the high level of satisfaction by the patients. MIS decompression groups had more positive responses to the satisfaction survey than the microscopic decompression group, and such results in MIS groups exceed those reported for previous other lumbar decompression techniques [4, 5, 7, 34]. These findings appeared to be related not only to the minimal operative skin scar from MIS technique but also to the minimal immediate postoperative back pain, short hospital stays from fast recovery, and early return to normal life owing to the minimal invasiveness of MIS decompression, which are all mentioned in previous articles as merits of MIS surgery [7, 25, 32, 35, 36].

*4.2. Decompression Ability and Radiological Outcome.* Previous reports have presented that one of the drawbacks in MIS bilateral decompression via unilateral approach is incomplete decompression, especially, contralateral root decompression [37, 38]. It is due to very limited operative view and working space to manipulate the surgical instruments during the operation. However, the results of this study showed competent decompression ability of MIS techniques equal to the traditional microscopic technique. In the current study, the radiologic analysis of the canal diameter changes proved

Table 4: Comparison of surgical outcome.

| | Endoscopic (N=164) | Tubular (N=34) | Microscopic (N=72) | $p$ value |
|---|---|---|---|---|
| Avg EBL(ml) | 35.34±28.87† | 72±23.21(44-350) | 134.3±35.34 | 0.087 |
| Avg. surgery time (minutes/ level) | 84.17±34.70 | 66.12±15.93 | 52.22±19.07 | ≤0.001∗ |
| Avg. hospital stay (days) | 2.12±1.68 | 2.83±1.99 | 4.85±1.86 | ≤0.001∗ |
| Serum CPK (IU/L) ( POD#1 day – Preoperative) | 66.38±63.61 | 137.5±101.00 | 120 ±116.89 | 0.030∗ |
| Perioperative complication Rate (% of patients) | 7.9% | 8.8% | 8.3% | NS |
| | Dura tear (4) Dysthesia (7) Motor weakness (1) Disc recur(1) | Postop. Hematoma (1) Dysthsia(1) Disc Recur(1) | Postop. Hematoma(1) Dysthesia(4) Dura tear (1) | |

NS=not significant; Avg=average; EBL=estimated blood loss; CPK=creatine phosphokinase; POD=postoperative day; ∗=statistically significant, †=only hemovac drainage.

the satisfactory decompression ability of MIS techniques. There was no revision case in groups E and T due to the incomplete decompression, which also supports the efficacy of MIS decompression in the lumbar stenosis. In the percutaneous endoscopic lumbar decompression, the limited surgical visibility through the endoscopic channel and the unfamiliarity with the use of endoscopic instruments can prevent complete decompression of spinal canal and bilateral recess area during the early stage of the learning curve.

Intraoperative bleeding, although it is minimal, can induce blurred operative view, which also could be the obstacle to proceed with the decompressive procedure. However, as we became familiar with the endoscopic lumbar anatomy and the basic usage of the endoscopic instruments such as high speed drills and punches, we were able to perform a thorough bilateral decompression. Strict bleeding control by RF bipolar and proper adjustment of hydrostatic pressure by irrigative pump system were the keys to maintain a clear operative view until complete decompression was achieved. Variable endoscopic operative views caused by tilting and rotating the endoscope enabled complete exploration around the main pathology without difficulty.

*4.3. Serum CPK.* The role of elevated serum CPK levels as a biochemical indicator of muscle injury has been shown in previous studies. A significant reduction in postoperative creatine phosphokinase was reported among participants treated with MIS techniques when compared with conventional laminectomy [39–41]. In this study, endoscopic decompression group showed the tendency of less increase of CPK enzyme compared to microscopic decompression group. Although it was statistically not significant, considering such an inclination was more evident as the number of decompressed levels increased, we assert that endoscopic decompression technique has more advantages to save paraspinal muscle damage than traditional microscopic decompression technique. Further study by recruiting more patients to this data would be needed to prove significant less invasiveness of endoscopic decompression technique compared with traditional laminectomy by the parameter of serum CPK.

Previous several authors reported the variable patterns of serum CPK change in tubular lumbar decompression, but the relationship between increased serum CPK level and postoperative lumbar back pain remained controversial [6, 16, 32]. Curiously enough, in this study, tubular decompression group showed significantly more increase of serum CPK compared to endoscopic decompression group. We think it may be related to the difficulty in inserting the working tube in the minimally invasive way or be caused by the initial surgical step to remove some parts of the muscle inside the tube after the insertion of a tubular retractor to acquire clear operative field. Although such change of CPK in tubular decompression group did not affect the postoperative clinical outcome, such as immediate postoperative back pain and hospital stay, compared to other two groups in this study, this finding is worthy of the attention.

*4.4. Learning Curve and Operative Time.* Most MIS techniques have steep learning curves and need longer operation time, especially, in the early stage of the learning curve [5, 28, 42, 43]. MIS techniques of ULBD have a very narrow vision and physical space inside the cannula which has a small diameter. Such limitations can cause prolonged operation time and intraoperative complications. Particularly with the endoscopic lumbar spine surgery, beginner surgeons who are not familiar with endoscopic surgical anatomy have difficulty manipulating endoscopic operative equipment, which can lead to long operation time. In this study, mean operative time in endoscopic decompression group was longer (E: 84.17 minutes/level, T: 66.12 minutes/level, and M: 52.22 minutes/level) than those in the other two decompression techniques. This

was due to the surgeon who performed the endoscopic decompression was in the learning curve. However, the chronological analysis of the operative time in the endoscopic decompression group showed the operative time decreased with more cases (initial third (55 cases): 102.1 minutes, second third (55 cases): 85.9 minutes, and last third (54 cases): 66.60 minutes). Percutaneous endoscopic lumbar decompression is a complex and technically demanding procedure associated with a steep learning curve and needs considerable experience to achieve an adequate neural decompression. However, from reviewing the chronological change of the operative time in the endoscopic decompression group, we could conclude that the endoscopic decompression technique has reasonable operative time compared to other two techniques and can be learned with time.

*4.5. Perioperative Complications.* There have been concerns about a number of potential disadvantages and complications in the MIS decompression techniques for the lumbar stenosis. Some authors have asserted that limited visualization of the critical neural structures and the difficult handling of operative instruments in MIS decompression techniques may be responsible for the higher rates of complications such as dura tear or neural injury. However, in this study, the incidence of surgery-related complications in MIS decompression groups was not high compared with the microscopic decompression group (group E: 7.9%, group T: 8.8%, and group M: 8.3%) and comparable to those reported in previous studies of other MIS decompression techniques [3, 6, 9–11, 15, 30, 44]. Considering the surgeon who performed the endoscopic decompression was in the learning curve, these results reflect MIS surgery to be a relatively safe and reliable method to decompress stenotic spinal canal and lateral recess. In the current analysis, there were six cases of dura tears (2.4 %) in group E, no case in group T and a case in group M (1.3%). One case of dura tear in microscopic decompression group was managed with suture with No 5. Prolen. Most cases of dural tears in endoscopic decompression were repaired by applying a gelfoam and TachoSil sealant patch (Baxter Healthcare Corporation, Deerfield, IL, USA) during the operation and ABR afterwards, because those were small nicks. Although the incidence of dura tear in endoscopic decompression group was higher than other groups, most cases occurred in the surgeon's early stage of learning curve, and its incidence was comparable with previous literature findings [5, 9, 10, 17, 30, 44, 45]. Constant saline irrigation through a working channel provided more epidural working space between the neural structures and the surrounding soft tissues during the endoscopic decompression, which made it easy to differentiate and manipulate the related structures in the narrow operative fields. Such an advantage of the acquisition of better intraoperative view by irrigative pressure in the endoscopic decompression helped to decrease the complication rate. No case in the endoscopic decompression group resulted in negative consequences such as persistent CSF leakage or revision surgery in this study.

We identified a total of 12 cases of transient postoperative dysthesia and a case of motor weakness in this study. There was no significant difference in the incidence of neural injury among the three decompression techniques. Reviewing these cases, excessive retraction of the neural structures without adequate adhesiolysis was considered as the major cause of the neural injury regardless of the decompressive methods. The usage of RF bipolar with high intensity was another cause of postoperative leg discomfort in the endoscopic decompression group. Minimal and delicate manipulation with beforehand adhesiolysis of the neural structures is important in achieving a favorable clinical outcome without intraoperative neural complications. Careful RF bipolar coagulation with adequate intensity is recommended to avoid postoperative dysthesia in the endoscopic decompression.

*4.6. Limitations.* This study was a retrospective study and not a randomized one with the different size of samples among the three groups. A prospective randomized study that compares each procedure with standardized preoperative data, which have even numbers of cases among groups, is required. Despite such shortcomings, current study showed obvious results that MIS decompression techniques have comparable outcome with traditional microscopic decompression technique or even superior outcome such as less immediate postoperative back pain and high patient satisfaction and acceptable complication rate compared with those of previous studies. Another weakness of this study is that the follow-up period was rather short. The real advantages of MIS techniques should be proven not only by short-term clinical and radiological outcomes (less immediate back pain, less increased CPK enzyme, and sufficient spinal canal decompression) but also longer-term results which can give real benefits to patients. The issues, compared to the traditional decompressive surgery, whether the minimally invasive decompressive surgery is advantageous to decrease the incidence of secondary operation due to postoperative instability and postoperative chronic back pain or not should be addressed in future long-term studies with more patients.

Each procedure was performed by three different surgeons. It may be attributed to intersurgeon variability in terms of experience and case load. Ideally, all cases should be performed by the same surgeon to minimize the influence of personal experience. However, all surgeons who performed surgeries in this study had already a great deal of traditional spinal surgery experience. Although the surgeon who performed the endoscopic decompression was in his learning curve, it was encouraging to find that the results from the endoscopic decompression group were comparable with the two other groups, which can imply good clinical feasibility of MIS technique. Although this study has many limitations, thinking collectively from the overall results, authors think that the results of this study suffice to prove the efficacy and clinical feasibility of MIS decompression techniques in the lumbar canal and lateral recess stenosis and to convince spine surgeons to apply this technique in their practice.

## 5. Conclusions

MIS lumbar decompression technique is clinically feasible and safe to treat the lumbar canal and lateral recess stenosis,

and it has many surgical advantages such as less muscle trauma, minimal postoperative back pain, fast recovery, and high patient satisfaction compared with traditional open microscopic technique.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## References


[1] H. Verbiest, "Results of surgical treatment of idiopathic developmental stenosis of the lumbar vertebral canal. A review of twenty-seven years' experience," *The Journal of Bone & Joint Surgery (British Volume)*, vol. 59, no. 2, pp. 181–188, 1977.

[2] S.-W. Hong, K. Y. Choi, Y. Ahn et al., "A comparison of unilateral and bilateral laminotomies for decompression of L4–L5 spinal stenosis," *The Spine Journal*, vol. 36, no. 3, pp. E172–E178, 2011.

[3] Y. Arai, T. Hirai, T. Yoshii et al., "A prospective comparative study of 2 minimally invasive decompression procedures for lumbar spinal canal stenosis," *The Spine Journal*, vol. 39, no. 4, pp. 332–340, 2014.

[4] C. Thomé, D. Zevgaridis, O. Leheta et al., "Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy," *Journal of Neurosurgery: Spine*, vol. 3, no. 2, pp. 129–141, 2005.

[5] K. Phan and R. J. Mobbs, "Minimally invasive versus open laminectomy for lumbar stenosis," *The Spine Journal*, vol. 41, no. 2, pp. E91–E100, 2016.

[6] G. M. Overdevest, W. Jacobs, C. Vleggeert-Lankamp, C. Thomé, R. Gunzburg, and W. Peul, "Effectiveness of posterior decompression techniques compared with conventional laminectomy for lumbar stenosis," *Cochrane Database of Systematic Reviews*, vol. 2015, no. 3, 2015.

[7] M. Rahman, L. E. Summers, B. Richter, R. I. Mimran, and R. P. Jacob, "Comparison of techniques for decompressive lumbar laminectomy: the minimally invasive versus the 'classic' open approach," *Minimally Invasive Neurosurgery*, vol. 51, no. 2, pp. 100–105, 2008.

[8] M. F. Oertel, Y. Ryang, M. C. Korinth, J. M. Gilsbach, and V. Rohde, "Long-term results of microsurgical treatment of lumbar spinal stenosis by unilateral laminotomy for bilateral decompression," *Neurosurgery*, vol. 59, no. 6, pp. 1264–1270, 2006.

[9] H. S. Kim, B. Paudel, J. S. Jang et al., "Percutaneous full endoscopic bilateral lumbar decompression of spinal stenosis through uniportal-contralateral approach: techniques and preliminary results," *World Neurosurgery*, vol. 103, pp. 201–209, 2017.

[10] J. H. Hwang, W. M. Park, and C. W. Park, "Contralateral interlaminar keyhole percutaneous endoscopic lumbar surgery in patients with unilateral radiculopathy," *World Neurosurgery*, vol. 101, pp. 33–41, 2017.

[11] M. Komp, P. Hahn, S. Oezdemir et al., "Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar versus microsurgical laminotomy technique: A prospective, randomized, controlled study," *Pain Physician*, vol. 18, no. 1, pp. 61–70, 2015.

[12] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: a prospective, randomized, controlled study," *Journal of Neurosurgery*, vol. 10, no. 5, pp. 476–485, 2009.

[13] C. Lee, K. Yoon, and J. Jun, "Percutaneous endoscopic laminotomy with flavectomy by uniportal, unilateral approach for the lumbar canal or lateral recess stenosis," *World Neurosurgery*, vol. 113, pp. e129–e137, 2018.

[14] S. Palmer, R. Turner, R. Palmer et al., "Bilateral decompression of lumbar spinal stenosis involving a unilateral approach with microscope and tubular retractor system," *Journal of Neurosurgery*, vol. 97, no. 2, pp. 213–217, 2002.

[15] M. Moisi, C. Fisahn, L. Tkachenko et al., "Unilateral laminotomy with bilateral spinal canal decompression for lumbar stenosis: a technical note," *Cureus*, vol. 8, no. 5, p. e623, 2016.

[16] M. Arts, R. Brand, B. van der Kallen, G. Lycklama à Nijeholt, and W. Peul, "Does minimally invasive lumbar disc surgery result in less muscle injury than conventional surgery? A randomized controlled trial," *European Spine Journal*, vol. 20, no. 1, pp. 51–57, 2011.

[17] Y. Hatta, T. Shiraishi, A. Sakamoto et al., "Muscle-preserving interlaminar decompression for the lumbar spine," *The Spine Journal*, vol. 34, no. 8, pp. E276–E280, 2009.

[18] Y.-H. Ho, Y.-K. Tu, C.-K. Hsiao, and C.-H. Chang, "Outcomes after minimally invasive lumbar decompression: a biomechanical comparison of unilateral and bilateral laminotomies," *BMC Musculoskeletal Disorders*, vol. 16, no. 1, p. 208, 2015.

[19] Y. Ahn, H.-K. Oh, H. Kim, S.-H. Lee, and H.-N. Lee, "Percutaneous endoscopic lumbar foraminotomy: An advanced surgical technique and clinical outcomes," *Neurosurgery*, vol. 75, no. 2, pp. 124–132, 2014.

[20] M. T. N. Knight, I. Jago, C. Norris, L. Midwinter, C. Boynes, and L. Acu, "Transforaminal endoscopic lumbar decompression & foraminoplasty: a 10 year prospective survivability outcome study of the treatment of foraminal stenosis and failed back surgery," *International Journal of Spine Surgery*, vol. 8, p. 21, 2014.

[21] K.-C. Choi, J.-S. Kim, D. C. Lee, and C.-K. Park, "Percutaneous endoscopic lumbar discectomy: Minimally invasive technique for multiple episodes of lumbar disc herniation," *BMC Musculoskeletal Disorders*, vol. 18, no. 1, p. 329, 2017.

[22] C.-W. Lee, K.-J. Yoon, S.-S. Ha, and J.-K. Kang, "Foraminoplastic superior vertebral notch approach with reamers in percutaneous endoscopic lumbar discectomy: technical note and clinical outcome in limited indications of percutaneous endoscopic lumbar discectomy," *Journal of Korean Neurosurgical Society*, vol. 59, no. 2, pp. 172–181, 2016.

[23] H. S. Kim and J. Y. Park, "Comparative assessment of different percutaneous endoscopic interlaminar lumbar discectomy (PEID) techniques," *Pain Physician*, vol. 16, no. 4, pp. 359–367, 2013.

[24] E. C. Benzel and R. D. Orr, "A steep learning curve is a good thing!," *The Spine Journal*, vol. 11, no. 2, pp. 131-132, 2011.

[25] G. Anichini, A. Landi, F. Caporlingua et al., "Lumbar endoscopic microdiscectomy: where are we now? an updated literature review focused on clinical outcome, complications, and rate of recurrence," *BioMed Research International*, vol. 2015, Article ID 417801, 14 pages, 2015.

[26] L. Cong, Y. Zhu, and G. Tu, "A meta-analysis of endoscopic discectomy versus open discectomy for symptomatic lumbar disk herniation," *European Spine Journal*, vol. 25, no. 1, pp. 134–143, 2016.

[27] B. Wang, G. Lü, A. A. Patel, P. Ren, and I. Cheng, "An evaluation of the learning curve for a complex surgical technique: the full endoscopic interlaminar approach for lumbar disc herniations," *The Spine Journal*, vol. 11, no. 2, pp. 122–130, 2011.

[28] J. Ahn, A. Iqbal, and B. T. Manning, "Minimally invasive lumbar decompression–the surgical learning curve," *The Spine Journal*, pp. 1–7, 2015.

[29] J. He, S. Xiao, Z. Wu, and Z. Yuan, "Microendoscopic discectomy versus open discectomy for lumbar disc herniation: a meta-analysis," *European Spine Journal*, vol. 25, no. 5, pp. 1373–1381, 2016.

[30] K. Sairyo, T. Sakai, K. Higashino, M. Inoue, N. Yasui, and A. Dezawa, "Complications of endoscopic lumbar decompression surgery," *Minimally Invasive Neurosurgery*, vol. 53, no. 4, pp. 175–178, 2010.

[31] E. Belykh, M. B. Giers, M. C. Preul, N. Theodore, and V. Byvaltsev, "Prospective comparison of microsurgical, tubular-based endoscopic, and endoscopically assisted diskectomies: clinical effectiveness and complications in railway workers," *World Neurosurgery*, vol. 90, pp. 273–280, 2016.

[32] R. Sasaoka, H. Nakamura, S. Konishi et al., "Objective assessment of reduced invasiveness in MED. Compared with conventional one-level laminotomy," *European Spine Journal*, vol. 15, no. 5, pp. 577–582, 2006.

[33] Y. Fu, B. Zeng, and J. Xu, "Long-term outcomes of two different decompressive techniques for lumbar spinal stenosis," *The Spine Journal*, vol. 33, no. 5, pp. 514–518, 2008.

[34] K. Iwatsuki, T. Yoshimine, and M. Aoki, "Bilateral interlaminar fenestration and unroofing for the decompression of nerve roots by using a unilateral approach in lumbar canal stenosis," *World Neurosurgery*, vol. 68, no. 5, pp. 487–492, 2007.

[35] H. S. Kim, R. Patel, B. Paudel et al., "Early outcomes of endoscopic contralateral foraminal and lateral recess decompression via an interlaminar approach in patients with unilateral radiculopathy from unilateral foraminal stenosis," *World Neurosurgery*, vol. 108, pp. 763–773, 2017.

[36] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Use of newly developed instruments and endoscopes: Full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach," *Journal of Neurosurgery: Spine*, vol. 6, no. 6, pp. 521–530, 2007.

[37] J. Hwa Eum, D. Hwa Heo, S. K. Son, and C. K. Park, "Percutaneous biportal endoscopic decompression for lumbar spinal stenosis: a technical note and preliminary clinical results," *Journal of Neurosurgery: Spine*, vol. 24, no. 4, pp. 602–607, 2016.

[38] G. Krzok, A. E. Telfeian, R. Wagner, C. P. Hofstetter, and M. Iprenburg, "Contralateral facet-sparing sublaminar endoscopic foraminotomy for the treatment of lumbar lateral recess stenosis: technical note," *Journal of Spine Surgery*, vol. 3, no. 2, pp. 260–266, 2017.

[39] M. O. Akçakaya, A. G. Yörükoğlu, A. Aydoseli et al., "Serum creatine phosphokinase levels as an indicator of muscle injury following lumbar disc surgery: Comparison of fully endoscopic discectomy and microdiscectomy," *Clinical Neurology and Neurosurgery*, vol. 145, pp. 74–78, 2016.

[40] L. Pan, P. Zhang, and Q. Yin, "Comparison of tissue damages caused by endoscopic lumbar discectomy and traditional lumbar discectomy: a randomised controlled trial," *International Journal of Surgery*, vol. 12, no. 5, pp. 534–537, 2014.

[41] K. Kim, T. Isu, A. Sugawara, R. Matsumoto, and M. Isobe, "Comparison of the effect of 3 different approaches to the lumbar spinal canal on postoperative paraspinal muscle damage," *World Neurosurgery*, vol. 69, no. 2, pp. 109–113, 2008.

[42] D. Y. Lee and S.-H. Lee, "Learning curve for percutaneous endoscopic lumbar discectomy," *Neurol. Med. Chir. (Tokyo)*, vol. 48, no. 9, pp. 383–388, 2008.

[43] D. Choi, C. Choi, J. Jung, S. Lee, and Y. Kim, "Learning curve associated with complications in biportal endoscopic spinal surgery: challenges and strategies," *Asian Spine Journal*, vol. 10, no. 4, pp. 624–629, 2016.

[44] V. K. Podichetty, J. Spears, R. E. Isaacs, J. Booher, and R. S. Biscup, "Complications associated with minimally invasive decompression for lumbar spinal stenosis," *Journal of Spinal Disorders & Techniques*, vol. 19, no. 3, pp. 161–166, 2006.

[45] M. Komp, P. Hahn, S. Ozdemir et al., "Operation of lumbar zygoapophyseal joint cysts using a full-endoscopic interlaminar and transforaminal approach," *Surgical Innovation*, vol. 21, no. 6, pp. 605–614, 2014.

Hindawi
BioMed Research International
Volume 2019, Article ID 5758671, 6 pages
https://doi.org/10.1155/2019/5758671

*Research Article*

# Posterolateral Endoscopic Lumbar Decompression Rotate-to-Retract Technique for Foraminal Disc Herniation: A Technical Report

**Eun Sang Soo**,[1] **Chachan Sourabh**,[2] **and Lee Sang Ho**[2]

[1]*Department of Orthopaedics, Wooridul Spine Hospital, Gangnam-gu, Seoul, Republic of Korea*
[2]*Department of Neurosurgery, Wooridul Spine Hospital, Gangnum-gu, Seoul, Republic of Korea*

Correspondence should be addressed to Eun Sang Soo; erupt0123@naver.com

Received 12 September 2018; Revised 9 January 2019; Accepted 14 January 2019; Published 17 February 2019

Guest Editor: Hyeun S. Kim



*Background and Study Aim*. Foraminal disc herniations present the unique surgical challenge for exiting nerve root retraction and decompression. The aim of current study is to describe an innovative maneuver and evaluate its usefulness for endoscopic decompression of foraminal disc herniations. *Material and Methods*. A retrospective review was performed including cases of foraminal disc herniations who underwent endoscopic discectomy utilizing the rotate-to-retract technique. Data on patient demographics and improvement in VAS/ODI scores were collected and analyzed statistically. *Results*. There were ten patients (three male; seven female) in the final analysis. Seven procedures were done at the L4-L5 level, two were done at the L5-S1 level, and one was done at the L3-L4 level. The average VAS scores improved from preoperatively 7.5 to postoperatively 4.4 ($p= 0.001$). The mean preoperative ODI was 67.8 and improved to 26.6 postoperatively ($p< 0.001$). None of the cases reported any neurological or dural complication. *Conclusion*. Foraminal disc herniations can be safely and adequately addressed endoscopically with the use of rotate-to-retract technique.

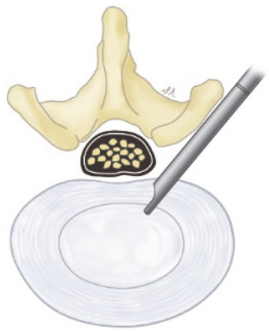
## 1. Introduction

Posterolateral endoscopic lumbar decompression (PLELD) is fast becoming the procedure of choice for surgical management of lumbar disc herniations [1–7]. Endoscopic discectomy techniques have produced surgical results similar to those of other discectomy techniques, while offering various advantages like avoidance of general anesthesia, preservation of paravertebral soft-tissues, faster rehabilitation, and better clinical results overall [1–7]. Cases of foraminal disc herniation (FDH) present the unique surgical challenge for exiting nerve root retraction and decompression [8–11]. Irrespective of the surgical technique used, the clinical outcome can be significantly affected by both technique of exiting nerve visualization/retraction and adequacy of decompression [8–11]. Use of appropriate exiting nerve retraction and visualization technique is paramount to adequate decompression [8–11]. The aim of this paper is to report an innovative maneuver, the "rotate-to-retract technique," for safe retraction and decompression of the exiting neural structures during PLELD in cases of FDH.

## 2. Material and Methods

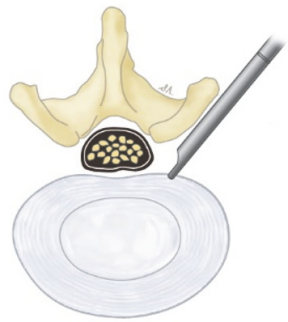
This study is a retrospective review of prospectively collected data extracted from local spine registry records. All surgeries were performed between February 2015 and October 2017 by a single spine surgeon (SSE). Inclusion criteria included all patients who were diagnosed with lumbar radiculopathy due to foraminal disc herniations, failed conservative therapy, and underwent PLELD. Exclusion criteria were revision cases, patients with multilevel radiculopathies/disc pathologies and calcified herniated discs. Data on patient demographics and level/side/duration of surgery were recorded. Clinical outcomes were evaluated using VAS/ODI scores collected preoperatively, postoperatively, and at final follow-up.

1.

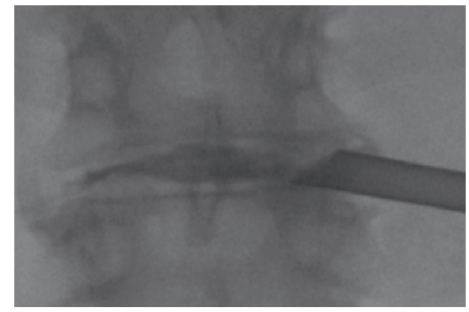


(a) Insertion of working channel at a steeper angle than usual PLELD

2.



(b) Working cannula is retrieved until its tip is outside the disc



(c) C-arm image of working cannula in place and discogram obtained

Figure 1

*2.1. Surgical Technique.* The procedure was performed under local anesthesia with mild sedation. The patient was positioned prone. A standard lumbar endoscopic instrument set (TESSYS®, Joimax®, Hamburg, Germany) was used. The surgical steps were as follows:

(1) The skin entry point and trajectory of the endoscope were planned based on the axial magnetic resonance (MR) images. The surgeon preferred to use a more direct trajectory towards the herniation resulting in the skin entry point about 7-8 cm from the midline with a steep angle of approach.

(2) The path of the endoscope was infiltrated with local anesthesia.

(3) An 18 G spinal needle was inserted under fluoroscopy guidance along the preplanned trajectory and needle tip is positioned in the spinal canal.

(4) Epidurography was performed to confirm the location of the neural structures.

(5) After confirmation of correct needle tip position, a guide wire was introduced via the spinal needle, followed by an obturator and a beveled working cannula (Figure 1(a)).

(6) The whole procedure was performed under fluoroscopy guidance. After satisfactory positioning of the working channel, a 25° endoscope was introduced.

(7) To safely approach the foraminal disc, rotate-to-retract technique was employed:

(a) The working cannula was retrieved until its tip was outside the disc (Figures 1(b) and 1(c)).

(b) The working cannula was rotated such that the tip and opening of the bevel were on the cranial side (Figure 2).

(c) It was then rotated clockwise, which resulted in spontaneous retraction of the exiting nerve root (Figure 3).

(d) The working channel was placed in the most lateral part of Kambin's triangle with its bevel tip retracting the exiting root (Figure 4).

3.

Figure 2: Working cannula is rotated such that tip and opening of bevel are on the cranial side.

4.

Figure 3: Working cannula is rotated clockwise.

Table 1: Demographic and operative data.

| Sr No. | Gender | Age | level | side | op time (min) |
|---|---|---|---|---|---|
| 1 | f | 80 | 45 | Right | 50 |
| 2 | f | 62 | 56 | Left | 55 |
| 3 | f | 64 | 45 | Right | 60 |
| 4 | m | 75 | 34 | Left | 45 |
| 5 | m | 44 | 45 | Right | 70 |
| 6 | f | 66 | 45 | Right | 50 |
| 7 | f | 68 | 45 | Right | 45 |
| 8 | f | 47 | 45 | Right | 35 |
| 9 | f | 45 | 45 | Right | 55 |
| 10 | m | 73 | 56 | Right | 60 |

5.

Figure 4: Working channel is placed in most lateral part of Kambin's triangle and bevel is retracting the exiting root.

(e) By rotating the opening of the working channel to the lateral side, endoscopic forceps could be used to grasp the extra-foraminal disc herniation underneath the exiting root (Figures 5(a) and 5(b)).

(8) Rest of the discectomy was performed and concluded in the standard manner.

(9) Intraoperatively, exiting nerve root decompression could be assessed by direct inspection with endoscope (Figure 6).

*2.2. Statistical Analysis.* Pre- and postoperative VAS and ODI scores were calculated and statistically compared using paired t-tests. P value <0.05 was considered statistically significant. All analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.).

## 3. Results

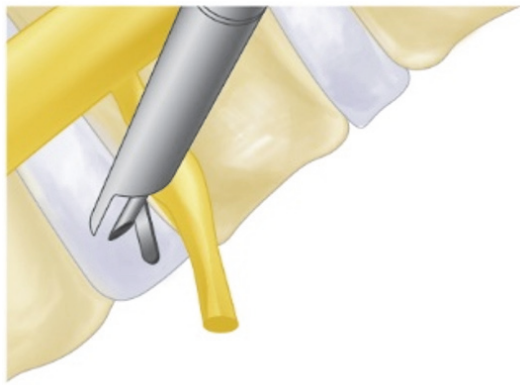
There were ten patients (three male; seven female) in the final analysis, with an average age of 62.4 years (range 44-80 years) [Table 1]. The average duration of surgery was 52.5 minutes (range 35-70 minutes). Of the ten cases, six were operated on the right side and rest on the left side. Seven procedures were done at the L4-L5 level, two were done at the L5-S1 level, and one was done at the L3-L4 level. The mean follow-up period was 5.6 months (range 4-8 months). The average VAS scores changed from preoperatively 7.5 (range 6-8) to postoperatively 4.4 (range 2-8). The change in VAS scores was statistically significant ($p= 0.001$). The mean preoperative ODI was 67.8 (range 42–84) and improved to 26.6 (range 16-55) postoperatively, which was statistically significant ($p< 0.001$) [Table 2]. All the patients underwent an immediate postoperative MRI, which showed successful removal of the herniated disc fragment and good decompression of the exiting nerve root in all the cases (Figure 7). None of the cases reported any neurological or dural complication. All the cases showed good improvement in ODI scores. All except one case reported good postoperative improvement in pain scores.

## 4. Discussion

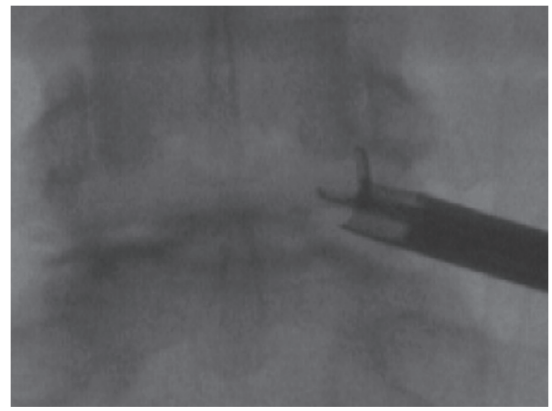
In the current series, use of rotate-to-retract technique during PLELD resulted in complete removal of the FDH. This technique offered effective and safe retraction of the exiting nerve root in the Kambin's triangle [12]. The authors have reported use of beveled working cannula to effectively remove the inferiorly migrated disc herniation using transforaminal approach [13]. With all the steps of rotate-to-retract technique, surgeon can address a variety of disc lesions: canalicular, foraminal, axillary (exiting root), upmigrated, and extra-foraminal (underneath the medial border of exiting nerve root).

Compared with central disc herniations, foraminal disc herniation discectomies (microscopic/endoscopic) have a reportedly higher postoperative incidence of remnant radicular pain and paresthesia [14]. The authors postulate that the inferior outcomes of FDH discectomies can be attributed to DRG (dorsal root ganglion) manipulation. Furthermore,

6.



(a) Rotate the opening of working channel to the lateral side and forceps can grasp extraforaminal disc underneath the exiting root.



(b) C-arm image showing opening of working channel to the lateral side and forceps can grasp extraforaminal disc underneath the exiting root

Figure 5

Table 2: Clinical outcome data.

| Sr No. | preop-VAS | preop ODI | postop-VAS | postop-ODI | f/u (month) |
|---|---|---|---|---|---|
| 1 | 8 | 82 | 3 | 20 | 6 |
| 2 | 7 | 75 | 3 | 18 | 6 |
| 3 | 8 | 80 | 8 | 46 | 6 |
| 4 | 8 | 82 | 5 | 55 | 6 |
| 5 | 6 | 42 | 4 | 24 | 6 |
| 6 | 7 | 54 | 2 | 33 | 4 |
| 7 | 8 | 73 | 5 | 16 | 4 |
| 8 | 7 | 53 | 3 | 20 | 4 |
| 9 | 8 | 53 | 8 | 18 | 8 |
| 10 | 8 | 84 | 3 | 16 | 6 |

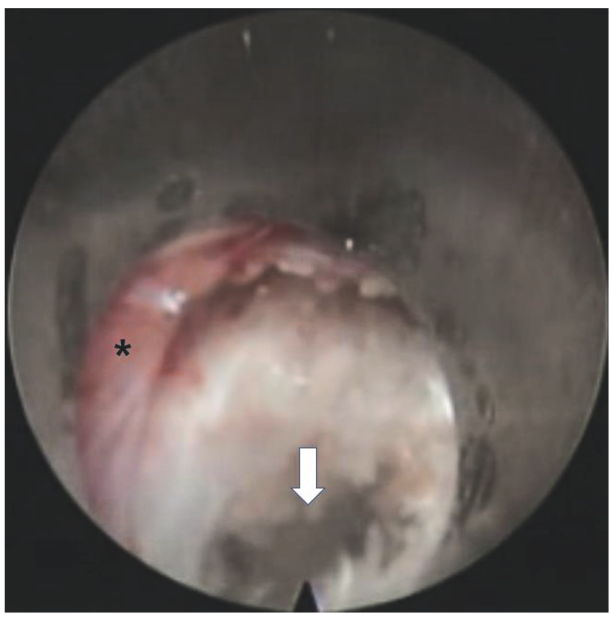
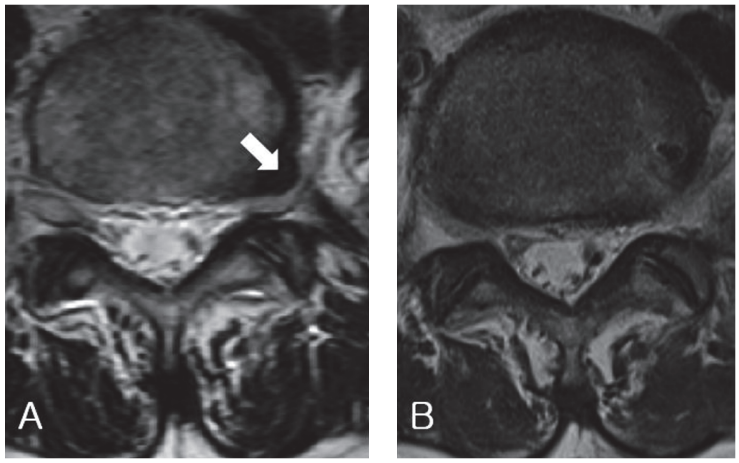



Figure 6: Endoscopic image showing exiting nerve root (∗) and disc space (arrow) after decompression.

removal of FDH can result in disc height decrement, segmental instability, and foraminal stenosis [7, 11, 12].

The term foraminal disc herniation (FDH) is interchangeably used with far lateral, extra-foraminal, and extreme lateral disc herniations [8–11]. Since initial reporting of its clinical manifestations by Abdullah et al., both detection and treatment rates of FDH have increased consistently [11]. FDH is both a diagnostic dilemma and a surgical challenge [8–11]. The diagnosis is complicated by ambiguous clinical features mimicking a posterolateral disc at the level above [8–11]. Furthermore, as multilevel disc herniation is not uncommon, missing a foraminal nerve root compression is easy [8–11]. This also explains highly variable reported incidence of FDH (0.7-11% of all lumbar disc herniations) [8–11]. The advent of MRI has significantly increased FDH detection and successful surgical treatment rates [8–11].

The surgical management of FDH is challenging due to an anatomically constrained area with associated higher risk of neural injury and iatrogenic segment instability [8–11]. All of these features combined produce high chances of failed back surgery in cases of FDH [8–11]. Various modifications of standard open and microsurgical techniques have been described for the management of FDH [8–11, 15–18].




(a) (b)

Figure 7: (a) Pre-op axial MRI showing left-side extra-foraminal disc herniation (white arrow) at L5-S1 level. (b) Post-op axial MRI showing removal of extra-foraminal disc herniation.

The use of conventional midline open surgery approaches for FDH, although familiar and comfortable for surgeons, is surgically counterintuitive, requiring removal/exposure of central/paracentral structures for removing pathological material which is mainly extra-canalicular [8–11, 15–18]. Although paraspinal open surgical approaches make more sense surgically, they are unfamiliar to many surgeons and also pose a risk of iatrogenic instability of facet joints [8–11, 15–18]. Open transforaminal approaches give good exposure too but are more invasive, result in iatrogenic instability, and are associated with higher morbidity [11, 12]. Combined intra- and extra-canal open surgical approaches have also been described but are discouraged due to excessive soft-tissue dissection/retraction and longer operative times [8–11, 15–18]. Midline contralateral approaches have also been described to achieve good decompression of FDH but are associated with compression of neural structures [19].

Several studies have reported successful outcomes with endoscopic removal of FDH [8–11, 16]. PLELD offers the advantage of minimal soft-tissue disruption, no bone resection, less bleeding, low chances of iatrogenic instability, shorter operation times, and faster rehabilitation, but are limited by a smaller field of vision and constrained anatomy which significantly increases the risk of exiting nerve root injury and inadequate decompression [8–11, 16]. Various modifications and maneuvers have been described to overcome the specific surgical challenges associated with endoscopic removal of FDH [8–11, 16]. The use of a standard method to retract nerve roots safely and securely away from the operating field will help in minimizing the complications. Furthermore, a standardized and adequate nerve retraction technique may result in faster herniotomy and decrease in overall surgical time.

The above described rotate-to-retract technique is a simple-easy-to-learn maneuver involving the use of beveled end of the working cannula to safely retract the exiting nerve root in its axilla, permitting complete removal of the pathological disc material. Use of the above-mentioned technique has resulted in good surgical outcomes in the current study. However, the small number of cases analyzed and lack of comparison with other techniques may limit the utility of the current study. Further studies including a larger number of cases can help in identifying the role of various other factors like disc height, superior articular process encroachment, bony spur on the lower end plate of cranial vertebrae, and concomitant lateral recess stenosis. The authors would also like to point out that this technique is probably being used by many spine endoscopists but has never been formally described in literature. The authors believe that a standardized description of this useful technique would be helpful in teaching safer methods of endoscopic spine surgery to beginners.

## Data Availability

The data used to support the findings of this study are included within the article in the form of table (Table 1).

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Supplementary Materials

Intraoperative endoscopy video showing rotate-to-retract technique being used during posterolateral endoscopy discectomy. *(Supplementary Materials)*

## References

[1] Y. Hirano, J. Mizuno, S. Numazawa, Y. Itoh, S. Watanabe, and K. Watanabe, "Percutaneous endoscopic lumbar discectomy (PELD) for herniated nucleus pulposus of the lumbar spine:

Surgical indications and current limitations," *Japanese Journal of Neurosurgery*, vol. 26, no. 5, pp. 346–352, 2017.

[2] J. Du, X. Tang, X. Jing, N. Li, Y. Wang, and X. Zhang, "Outcomes of percutaneous endoscopic lumbar discectomy via a translaminar approach, especially for soft, highly downmigrated lumbar disc herniation," *International Orthopaedics*, vol. 40, no. 6, pp. 1247–1252, 2016.

[3] C. W. B. Peng, W. Yeo, and S. B. Tan, "Percutaneous endoscopic discectomy: clinical results and how it affects the quality of life," *Journal of Spinal Disorders & Techniques*, vol. 23, no. 6, pp. 425–430, 2010.

[4] M.-J. Kim, S.-H. Lee, E.-S. Jung et al., "Targeted percutaneous transforaminal endoscopic diskectomy in 295 patients: comparison with results of microscopic diskectomy," *World Neurosurgery*, vol. 68, no. 6, pp. 623–631, 2007.

[5] A. E. Telfeian, A. Veeravagu, A. A. Oyelese, and Z. L. Gokaslan, "A brief history of endoscopic spine surgery," *Neurosurgical Focus*, vol. 40, no. 2, p. E2, 2016.

[6] H. H. Dasenbrock, S. P. Juraschek, L. R. Schultz et al., "The efficacy of minimally invasive discectomy compared with open discectomy: a meta-analysis of prospective randomized controlled trials: clinical article," *Journal of Neurosurgery: Spine*, vol. 16, no. 5, pp. 452–462, 2012.

[7] L. Pan, P. Zhang, and Q. Yin, "Comparison of tissue damages caused by endoscopic lumbar discectomy and traditional lumbar discectomy: a randomised controlled trial," *International Journal of Surgery*, vol. 12, no. 5, pp. 534–537, 2014.

[8] N. E. Epstein, "Management of far lateral lumbar disc herniations," *Schmidek and Sweet Operative Neurosurgical Techniques*, pp. 1871–1882, 2012.

[9] J.-S. Jang, S.-H. An, and S.-H. Lee, "Transforaminal percutaneous endoscopic discectomy in the treatment of foraminal and extraforaminal lumbar disc herniations," *Journal of Spinal Disorders & Techniques*, vol. 19, no. 5, pp. 338–343, 2006.

[10] G. Choi, S.-H. Lee, A. Bhanot, P. P. Raiturker, and Y. S. Chae, "Percutaneous endoscopic discectomy for extraforaminal lumbar disc herniations: extraforaminal targeted fragmentectomy technique using working channel endoscope," *The Spine Journal*, vol. 32, no. 2, pp. E93–E99, 2007.

[11] S. M. Lew, T. F. Mehalic, and K. L. Fagone, "Transforaminal percutaneous endoscopic discectomy in the treatment of far-lateral and foraminal lumbar disc herniations," *Journal of Neurosurgery*, vol. 94, 2 Suppl, pp. 216–220, 2001.

[12] R. Hoshide, E. Feldman, and W. Taylor, "Cadaveric analysis of the kambin's triangle," in *Cureus*, J. R. Adler, Ed., vol. 8, no.2, p. e475, 2016.

[13] S. S. Eun, S.-H. Lee, and H. Y. Erken, "Transforaminal percutaneous endoscopic lumbar diskectomy for downmigrated disk herniations: lever-up, rotate, and tilt technique," *Journal of Neurological Surgery, Part A: Central European Neurosurgery*, vol. 79, no. 2, pp. 163–168, 2018.

[14] K. Maio and M. Yoshida, "Clinical outcomes of microendoscopic discectomy for extraforaminal lumbar disc herniatin," in *State of the Art of Minimally Invasive Spine Surgery*, A. Dezawa, P. Q. Chen, and J. Y. Chung, Eds., Springer, Tokyo, Japan, 2005.

[15] K. Salame and Z. Lidar, "Minimally invasive approach to far lateral lumbar disc herniation: Technique and clinical results," *Acta Neurochirurgica (Wien)*, vol. 152, no. 4, pp. 663–668, 2010.

[16] J. E. O'Toole, K. M. Eichholz, and R. G. Fessler, "Minimally invasive far lateral microendoscopic discectomy for extraforaminal disc herniation at the lumbosacral junction: cadaveric dissection and technical case report," *The Spine Journal*, vol. 7, no. 4, pp. 414–421, 2007.

[17] M. Yoshimoto, T. Iwase, T. Takebayashi, K. Ida, and T. Yamashita, "Microendoscopic discectomy for far lateral lumbar disk herniation: less surgical invasiveness and minimum 2-year follow-up results," *Journal of Spinal Disorders & Techniques*, vol. 27, no. 1, pp. E1–E7, 2014.

[18] L. V. Berra, D. Foti, A. Ampollini, G. Faraca, N. Zullo, and C. Musso, "Contralateral approach for far lateral lumbar disc herniations: A modified technique and outcome analysis of nine patients," *The Spine Journal (Phila Pa 1976)*, vol. 35, no. 6, pp. 709–713, 2010.

[19] E. Zekaj, C. Menghetti, C. Saleh et al., "Contralateral interlaminar approach for intraforaminal lumbar degenerative disease with special emphasis on L5-S1 level: A technical note," *Surgical Neurology International*, vol. 7, p. 88, 2016.

Hindawi
BioMed Research International
Volume 2019, Article ID 6509409, 9 pages
https://doi.org/10.1155/2019/6509409

*Clinical Study*

# Percutaneous Endoscopic Lumbar Discectomy Assisted by O-Arm-Based Navigation Improves the Learning Curve

**Shengxiang Ao, Junlong Wu, Yu Tang, Chao Zhang, Jie Li, Wenjie Zheng, and Yue Zhou**

*Department of Orthopaedics, The Second Affiliated Xinqiao Hospital of Army Medical University, Chongqing 400037, China*

Correspondence should be addressed to Wenjie Zheng; 120198336@qq.com and Yue Zhou; happyzhou@vip.163.com

Received 8 August 2018; Accepted 31 December 2018; Published 10 January 2019

Academic Editor: Giuseppe Piccinni



*Objective*. There is a steep learning curve with traditional percutaneous endoscopic lumbar discectomy (PELD). The aim of this study is to assess the safety and efficacy of PELD assisted by O-arm-based navigation for treating lumbar disc herniation (LDH). *Methods*. From September of 2017 to January of 2018, 118 patients with symptomatic LDH were enrolled in the prospective cohort study. The patients undergoing PELD with O-arm-based navigation technique were defined as group A (58 cases), and those undergoing traditional X-ray fluoroscopy method were defined as group B (60 cases). We recorded the operation time, cannula placement time, radiation exposure time, visual analog scale (VAS), Oswestry Disability Index (ODI), and Macnab criteria score of the 2 groups. *Results*. The average operation time (95.21 ± 19.05 mins) and the cannula placement time (36.38 ± 14.67 mins) in group A were significantly reduced compared with group B (operation time, 113.83 ± 22.01 mins, $P<0.001$; cannula placement time, 52.63 ± 17.94 mins, $P<0.001$). The learning curve of PELD in group A was steeper than that in group B and was lower in the relatively flat region of the end. There were significant differences of the clinical parameters at different time points (VAS of low back, $P < 0.001$; VAS of leg, $P < 0.001$; and ODI, $P < 0.001$). The VAS scores for low back pain and leg pain improved significantly in both groups after surgery and gradually improved as time went by. No serious complication was observed in any patients in either group. *Conclusion*. The study indicated that PELD assisted by O-arm navigation is safe, accurate, and efficient for the treatment of lumbar intervertebral disc herniation. It reshaped the learning curve of PELD, reduced the difficulty of surgery, and minimized radiation exposure to surgeons. This study was registered at Chinese Clinical Trail Registry (Registration Number: ChiCTR1800019586).

## 1. Introduction

Minimally invasive spine surgical techniques are constantly developing and progressively becoming common techniques for treating lumbar disk herniation (LDH) [1, 2]. Particularly, percutaneous endoscopic lumbar discectomy (PELD) could have less muscular injury and bleeding, less scar formation within the spinal canal, and shorter hospital day, compared with open discectomy [3, 4]. Therefore, PELD has been widely used in lumbar discectomy surgery.

Nevertheless, the traditional PELD technique has a steep learning curve [5], needing surgeons' tough training to overcome it. Design and intraoperative application on the proper trajectory of the puncture for foraminoplasty are highly experience- and technique-demanding. Some cases with high iliac crest or severe migration would magnify the difficulty of puncture, even for skilled surgeons [6, 7]. Reducing the operating difficulty, increasing the accuracy of puncture, and reducing the radiation exposure to both patients and medical staff are the common goals shared by every surgeon.

Along with the development of medicine and technology, navigation has been applied in spine surgery [8]. Under image guidance systems, surgeons can get a 3-dimensional (3D) anatomy structure of spine or the multiplanar imaging reconstruction, and surgical instruments can be tracked in real time for 3D space. Previous studies have described successful navigation-assisted surgery in the cervical vertebrae, which is a safe and effective option for cervical radiculopathy [9]. However, there were few studies published about O-arm-based navigation in PELD. The feasibility, security, and accuracy of navigation in lumbar are rarely reported.

In this study, we present a surgical technique of PELD assisted by an O-arm-based navigation system and explore the learning curve and clinical outcomes between navigation and non-navigation group in prospective consecutive case series of LDH.

## 2. Materials and Methods

*2.1. Patients.* From September of 2017 to January of 2018, 118 patients with symptomatic LDH received PELD by two surgeons were enrolled in the study. For reducing the experimental bias, the two junior surgeons were blinded to the study. They did not know the purpose and specifics of this study. Both of the surgeons had 4-year rich surgical experience in conventional open spinal surgery with the same medical background, and both of them could complete microendoscopic discectomy (MED) independently. Before conducting PELD on their own, they had been trained systematically for several weeks by the same senior surgeon, using the same method, including 3 PELD cases of hand-holding practical teaching.

The inclusion criteria were (1) age≥18 and ≤70 years; (2) typical clinical symptoms and signs of mono-radiculopathy LDH; (3) concordant imaging evidence of single LDH (limited to L3-4, L4-5, or L5-S1), such as computed tomography (CT) and magnetic resonance imaging (MRI); and (4) conservative therapy for at least 3 months before surgery. The exclusion criteria were (1) serious underlying disease or mental illnesses; (2) severe central stenosis, cauda equina syndrome, spinal instability, active infection, and serious calcified fragments; (3) previous lumbar treatment with spinal surgery, ozone intervention, or radiofrequency ablation; and (4) unwilling or unable to participate in treatment and complete follow-up.

The patients undergoing PELD with O-arm-based navigation technique were defined as group A (58 cases), and those undergoing traditional X-ray fluoroscopy method were defined as group B (60 cases). The mean follow-up period was 9 months and all patients completed at least 7 months of follow-up.

This prospective clinical contrast study was approved by the Medical Ethics Committee of the Second Affiliated Hospital of Army Medical University and it was registered at Chinese Clinical Trail Registry (Registration Number: ChiCTR1800019586). All patients had signed consent forms before the surgery.

*2.2. Surgical Tools.* The O-arm and computer-assisted navigation system (O-arm Surgical Imaging System and Stealth-Station; Medtronic, Inc., Minneapolis, Minnesota, USA), the spine transforaminal endoscope system (TESSYS instrument system; Joimax, Inc., Irvine, California, USA), the patented specially designed ZESSYS double-cannula instrument (Bosscom, Inc., Chongqing, China) for targeted foraminoplasty, and tip-flexible electrode bipolar radiofrequency system (Elliquence LLC, Baldwin, New York, USA) were used in PELD.

*2.3. Surgical Technique*

*2.3.1. O-Arm-Based Navigation (Group A) Surgical Procedure.* The patient was placed prone on the radiolucent table. The O-arm Surgical Imaging System and Stealth-Station (Medtronic, Inc., Minneapolis, Minnesota, USA) were used for intraoperative stereotactic navigation (Figure 1(a)). After local anesthesia by 0.5% lidocaine, the reference frame was fixed on the contralateral iliac crest, using two Kirschner wires of 2.0mm diameter (Figure 1(b)). An intraoperative CT scan and 3D image were obtained by the O-arm with a medium dose (13s) of irradiation to reduce the radiation exposure to patient. The CT images data were rapidly transferred to the navigation system. Then the surgeon could get the multiplanar imaging reconstructions in both the axial and sagittal planes, traditional X-ray-like anteroposterior and lateral views, and even 3D image of the lumbar spine. And the surgeon could choose any images above, depending on his/her own habit. The final step of navigation preparation was the registration of surgical instruments, which could be tracked in real time. The entire procedure including reference frame fixation, scan, image transfer, and tools registration could take less than 10 minutes.

In navigation image, the tip of probe could be extended virtually along itself. With the aid of the sagittal reconstructions aimed at tip of superior articular process (SAP) and the axial views pointing over the anteriolateral margin of facet joint, the entire puncture trajectory targeted at tip of SAP could be designed accurately and proper skin entry point was selected easily (Figure 1(c)). Possible bony obstruct including high iliac crest and hypertrophic transverse process can be easily avoided in navigation views.

The entire surgery was performed under local anesthesia and optional narcotic sedation. A 0.7 cm incision was then made in the skin. A total amount of 15-30 mL of 0.5% lidocaine was infiltrated in the puncture trajectory through the trocar-like puncture probe (Figure 1(d)). With the help of navigation, when the probe was advanced docking on the lateral aspect of facet joint, it could easily slide into foramen along the anterior aspect of SAP. A 2 mm rod or Kirschner wire was introduced into foramen through the trocar probe and was slightly hammered to fix itself on the posterior aspect of the distal vertebra. After the sequential dilation, a patented double-cannula device named ZESSYS (Figure 1(e)) specially designed for navigation was then introduced to dock on the lateral aspect of facet joint.

The ZESSYS targeted foraminoplasty instrument offered variable options of facet-cutting amount and adjustable foraminoplasty site. Furthermore, the Kirschner wires in smaller tube provided a fixed pivot to avoid accidental instrument sliding during facet-cutting on facet joint. Under real-time navigation views guidance, the optimal foraminoplasty trajectory on SAP for intracanal exposure and neurological decompression based on different clinical needs could be easily designed and obtained. Depth of reamer/bone drill could also be easily monitored under navigation guidance to avoid possible intracanal neurological element injury.

After proper foraminoplasty, the working canal was then inserted through dilator. Further operation was performed

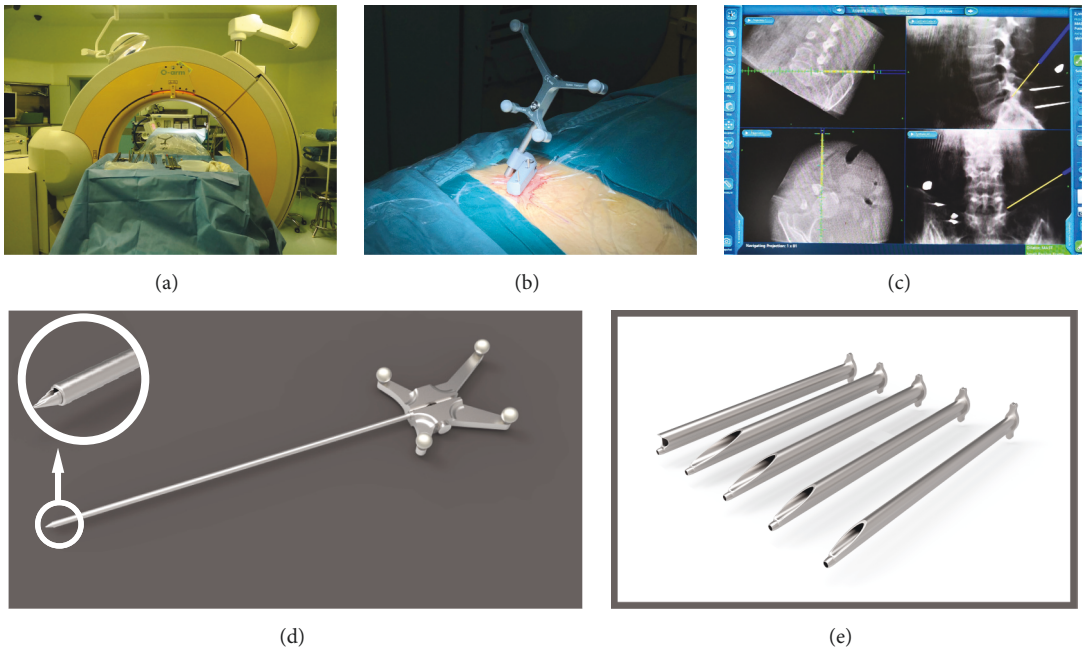


Figure 1: (a) Intraoperative 3D navigation system of O-arm. (b) The reference frame was fixed on the contralateral iliac crest. (c) With the aid of the real-time navigation, the entire puncture trajectory could be designed accurately and easily. (d) The trocar-like puncture probe for navigation. (e) In the dual-cannula (ZESSYS), the thinner cannula could contain a guide Kirschner wire for fixation and larger cannula for bony abrasion by bone drill/trephine.

under visual control of a 5.9 mm endoscope and continuous fluid flow with 0.9% saline solution. Discectomy and nerve root decompression were performed as routine PELD procedure [10].

*2.3.2. Traditional X-Ray Fluoroscopy (Group B) Surgical Procedure.* This procedure was performed as routine PELD with the standard TESSYS technique [10].

*2.4. Clinical Assessment.* Basic patient information, such as gender, age, body mass index (BMI), follow-up time, and LDH location, was recorded. We also recorded operation time (for the navigation group, it included the time of the O-arm surgical imaging setup procedure), intraoperative cannula placement time, and radiation exposure time. The intraoperative cannula placement time was defined as the duration between the first puncture and the final placement of working cannula (for the navigation group, it was calculated from the first puncture of the reference frame fixation). The radiation exposure time of Group B was obtained from the G-arm at the end of each procedure. We measured Macnab score (excellent, good, fair, poor) at 7 months' follow-up, which was used to assess patients' satisfaction and functional outcomes, in addition to preoperative and postoperative visual analogue scale (VAS) (0-10) of leg and low back pain and Oswestry Disability Index (ODI) at the time points of 1 day, 3 months, and 7 months after surgery and subsequently if required.

*2.5. Statistical Analysis.* Statistical software SPSS18.0 (SPSS, Inc., Chicago, IL, USA) was used to conduct the statistical analysis. The differences of the clinical outcomes (VAS and ODI) between the 2 groups and the changes over time in each group were identified via repeated-measures analysis of variance generally. LSD test was used to confirm further the changes at different time points in the same group, and Student's t-test was used to confirm further the differences between the 2 groups at the same time points. The difference of measurement data that were demonstrated as the mean ± standard deviation (SD), such as age, BMI, operation time, and cannula placement time, was assessed by Student's t-test. Ranked data such as Macnab criteria were detected by Mann-Whitney U test. Calculator information, such as gender and level ratio, was analysed by Chi-square test. Statistical significance was set at a P value of $<0.05$.

The learning curve was fitted with 11 different curve estimation regression models (linear, logarithmic, inverse, quadratic, cubic, power, compound, S-curve, logistic, growth, and exponential) by SPSS 18.0, where "y" is the operative time and "x" is the chronological operation case number. The regression model of learning curve was finally set depending on the highest R value among the 11 related plots and being consistent with the actual situation.

## 3. Results

*3.1. Patient Demographic Characteristics.* One hundred and eighteen patients (group A, 58 patients; group B, 60 patients) who underwent PELD between September of 2017 and January of 2018 were consecutively enrolled in this study. No significant differences ($P > 0.05$) were detected in the

Table 1: Patient demographics of group A and group B.

| | Group A | Group B | P Value |
|---|---|---|---|
| **Gender (male: female)** | 39:19 | 37:23 | 0.527 |
| **Age (years)** | 45.19 ± 13.63 | 42.43 ± 12.36 | 0.252 |
| **BMI (kg/m$^2$)** | 24.42 ± 4.14 | 23.76 ± 3.80 | 0.372 |
| **Follow-up Time (months)** | 8.90 ± 1.46 | 9.02 ± 1.48 | 0.658 |
| **Levels** | | | 0.655 |
| L3-4 | 2 | 2 | |
| L4-5 | 26 | 22 | |
| L5-S1 | 30 | 36 | |

BMI: body mass index.

Table 2: Comparison of clinical outcomes in group A and group B.

| | Group A | Group B | P Value |
|---|---|---|---|
| **Operation time (mins)** | 95.21 ± 19.05 | 113.83 ± 22.01 | <0.001 |
| **Cannula placement time (mins)** | 36.38 ± 14.67 | 52.63 ± 17.94 | <0.001 |

Table 3: Comparison of follow-up outcomes in group A and group B.

| | Group A | Group B | P Value |
|---|---|---|---|
| **VAS of low back** | | | |
| Preoperative | 5.41 ± 2.24 | 4.98 ± 2.02 | 0.275 |
| 1 day | 2.38 ± 1.40∗ | 2.50 ± 1.36∗ | 0.636 |
| 3 months | 2.00 ± 1.08 ∗ | 1.85 ± 1.15∗ | 0.466 |
| 7 months | 1.53 ± 0.96∗ | 1.38 ± 0.96∗ | 0.394 |
| **VAS of leg** | | | |
| Preoperative | 6.14 ± 1.86 | 5.67 ± 1.50 | 0.132 |
| 1 day | 2.07 ± 1.21∗ | 2.30 ± 1.25∗ | 0.311 |
| 3 months | 1.83 ± 1.11∗ | 1.93 ± 1.06∗ | 0.597 |
| 7 months | 1.33 ± 1.11∗ | 1.22 ± 1.14∗ | 0.594 |
| **ODI** | | | |
| Preoperative | 58.97 ± 17.79 | 55.80 ± 14.66 | 0.293 |
| 1 day | 19.83 ± 6.59∗ | 18.87 ± 5.54∗ | 0.392 |
| 3 months | 16.86 ± 4.76∗ | 16.30 ± 4.97∗ | 0.531 |
| 7 months | 12.83 ± 5.83∗ | 13.37 ± 6.88∗ | 0.648 |
| MacNab criteria† | | | |
| 7 months | 35:16:6:1 | 30:20:8:2 | 0.249 |

∗Compared with preoperative, P<0.05.
†Excellent: good: fair: poor.
VAS: visual analog scale, ODI: Oswestry Disability Index.

preoperative demographics between group A and group B (Table 1).

*3.2. Clinical Outcomes.* As shown in Table 2, the average operation time (95.21 ± 19.05 minutes) and the cannula placement time (36.38 ± 14.67 minutes) in group A were significantly shorter compared with group B (operation time 113.83 ± 22.01 minutes, P < 0.001; cannula placement time, 52.63 ± 17.94 minutes, P < 0.001). The radiation exposure time of group A was 13 seconds as the O-arm's setting, and in group B it was 53.47 ± 9.42 seconds.

Depending on the results of repeated-measures analysis of variance, there were significant differences of the clinical parameters at different time points (VAS of low back, P < 0.001; VAS of leg, P < 0.001; and ODI, P < 0.001). The VAS scores for low back pain and leg pain and ODI scors improved significantly in both groups after surgery and gradually improved as time went by (Table 3). However, there were no significant differences between the 2 groups (VAS of low back, P = 0.469; VAS of leg, P = 0.706; and ODI, P = 0.354). The excellent and good rates of Macnab criteria were 87.93% in group A and 83.33% in group B. We found no significant difference in Macnab criteria between group A and group B (P = 0.249).

*3.3. Learning Curve.* In group A, the learning curve was characterized using an inverse regression analysis (y = 86.21+112.26/x, $R^2$ = 0.765, P < 0.001). As demonstrated in

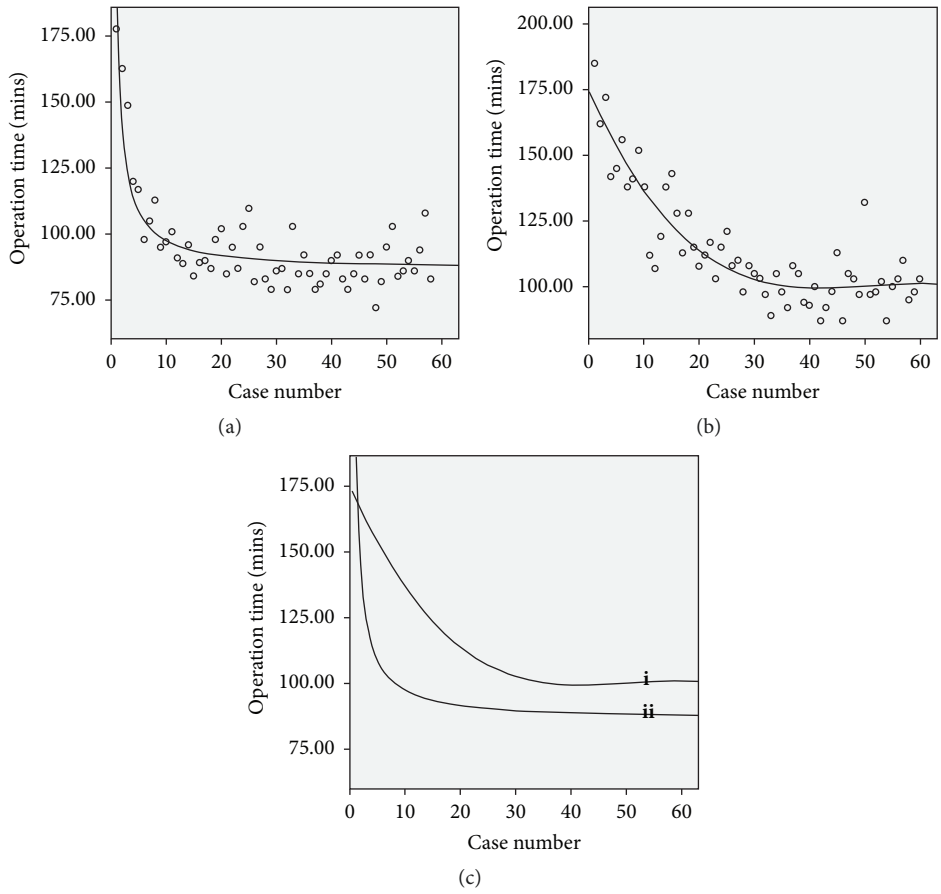



Figure 2: The learning curve of PELD. (a) Group A: $y = 86.21+112.26/x$. (b) Group B: $y = 174.483-4.712x+0.0966x^2-0.000641x^3$. (c) Draw Group A curve (ii) and Group B curve (i) in the same coordinate.

Figure 2(a), increasing case number was associated with fast decreasing operative time, and the curve tended to be stable in the end, where y = 95. Depending on the equation, $y = 86.21+112.26/x$, we deduced that from case 13 (x = 12.77, where y = 95) the doctor gradually reached a proficient phase.

In group B, the learning curve was characterized using a cubic regression analysis ($y = 174.483-4.712x+0.0966x^2-0.000641x^3$, $R^2 = 0.804$, $P < 0.001$). As demonstrated in Figure 2(b), increasing case number was associated with slowly decreasing operative time, and the curve tended to be stable in the end with a relatively flat region, where y = 102. Depending on the equation, $y = 174.483-4.712x+0.0966x^2-0.000641x^3$, we deduced that from case 32 (x = 31.26, where y = 102) the doctor gradually reached a proficient phase.

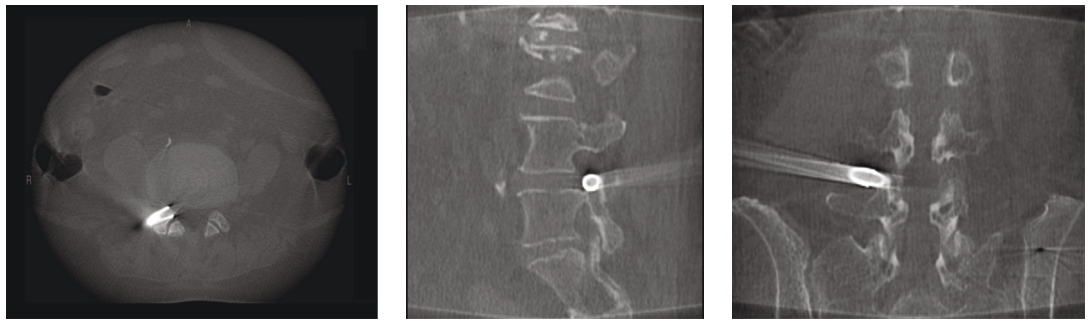
As demonstrated in Figure 2(c), the learning curve of PELD in group A was steeper than that in group B and was lower in the relatively flat region of the end.

*3.4. Operation Complications.* There were one case of recurrence and five cases of pain symptom remnants in group A, whereas there were two cases of recurrence and seven cases of pain symptom remnants in group B. No major complications including dura tear, spinal instability, vascular injury, surgical infection, or serious nerve injury were observed. Only one patient in group B suffered a slight nerve injury after the surgery at the L5-S1 level. He received conservative treatments such as neurotrophic drug and medium frequency pulse electrotherapy and recovered completely during the follow-up period. All included patients are still in long-term follow-up, without lost follow-up case.

## 4. Discussion

The traditional PELD poses great challenges to surgeons because the percutaneous transforaminal approach requires a proper point of entry and accurate puncture trajectory [10]. With conventional 2D fluoroscopy-guided discectomy, surgeons need their rich experience to complete an accurate puncture, which is also a challenge of anatomy and spatial imagination ability. It leads to a steep learning curve of PELD.

Reducing the operating difficulty and the risk of damage to the nerve root and vital tissue in puncture, simplifying the operating, and reducing the radiation exposure to both patients and medical staff, all the above are surgeons' constant goal. Lee et al. [11] found that proper pre-PELD training and patient selection may make the learning curve more acceptable. Chaichankul et al. [12] found that, because of the difficulty of PELD, the amount of surgical volume has an



(a) (b) (c)

Figure 3: The axial (a), sagittal (b), and coronal (c) images of intraoperative CT re-scan during foraminoplasty.

influence in the improvement of the effect of discectomy. Fan et al. [13] designed a mechanical navigation tool to reshape the learning curve of PELD.

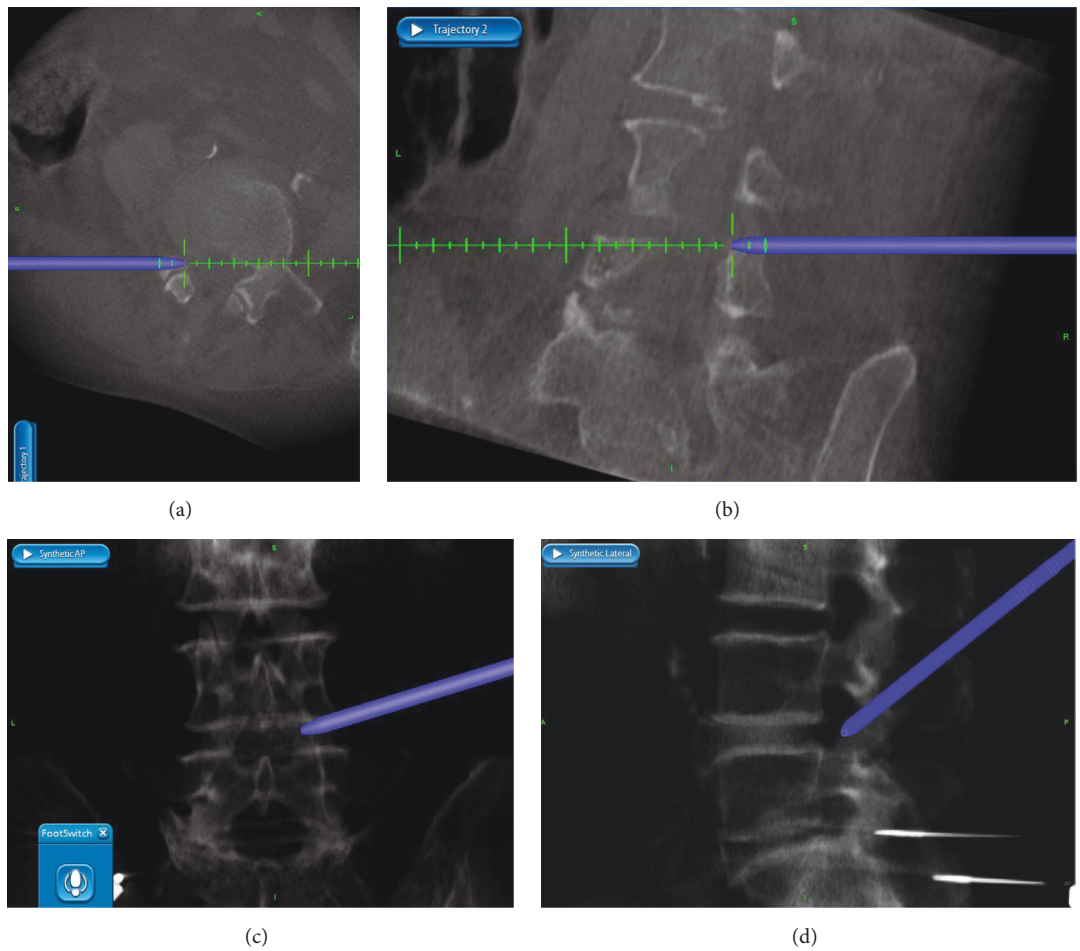
Along with the development of medicine and technology, computer-assisted 3D navigation has begun to be used in spine surgery [8, 14]. 3D navigation enables the surgeon to visualize the correct puncture trajectory at all times. Previous study reported that the reference frame was fixed on a spinous process, following the manufacturer's recommendations [15]. However, it led to unnecessary injury to spine. In our cases, the reference frame was fixed on the contralateral iliac crest. In order to verify the accuracy of navigation and keep safe when the reference frame was not attached on spine, during intraoperative foraminoplasty, we had re-scanned the surgical site in the preliminary clinical application of 10 cases before this prospective cohort study. The intraoperative CT re-scan by O-arm showed trephine cut off the anterior aspect of SAP accurately and it was safe to conduct foraminoplasty (Figure 3). At the same time, the intraoperative navigation images (Figure 4) were perfectly matched with intraoperative CT re-scan (Figure 3). After the working cannel was inserted, we re-scanned again by intraoperative radiograph of O-arm, to make sure of the ideal placement of working cannel (Figure 5). The re-scan results showed the accuracy loss is acceptable for this technique. In our study, PELD assisted by O-arm-based navigation is completely feasible in L3-4, L4-5, and L5-S1. The preoperative pain and functional scores were significantly improved at all time points after the PELD with navigation. There are no major complications observed. The excellent and good rates of Macnab criteria were 87.93% in navigation group.

The procedure from the initial punctures to the final placement of working cannel is the most difficult and critical part of the surgery [16]. Even the initial selection of entry point is also a huge challenge, because the surgeon needs to individually choose the correct distance from the midline of the spinous process based on the specific conditions of patients, such as height, weight, and anatomic feature. Choi et al. [17] reported a single-center experience of 10,228 cases, which showed that nonideal puncture and working cannel position were important factors leading to unsuccessful PELD. Nevertheless, O-arm-based navigation technique resolves the critical problem easily and simplifies the method of puncture. In this study, there was a significant reduction in the operation time and cannula placement time of navigation group. The learning curve of PELD in group A was steeper than that in group B, and the whole curve of navigation group was under that of the conventional group. With navigation technique, it took about 13 cases to arrive at a relatively stable proficiency condition, whereas it took about 32 cases with conventional technique. It should be noted that the steeper learning curve might not be a bad thing because beginners could master PELD technique faster with standard exercise on fewer patients [18, 19]. These positive results showed that the O-arm-based navigation system could help surgeons break the technique barriers brought by puncture and foraminoplasty portion and then reduce the technique difficulties of PELD.

In the first few cases of the navigation group, the operation time went far beyond the average time (95 minutes). It is mainly due to the nonproficiency of computer operation and poor cooperation with the technician. After a transient adaptation, the whole procedure including reference frame fixation, scan, image transfer, and registration can take less than 10 minutes. The average operation time of navigation group was about 95 minutes, which is consistent with or less than other previous studies [11, 12, 19, 20].

In conventional procedure, puncture, foraminoplasty and placement of the cannula were performed by trial-and-error manner, which is challenging for even skilled spine surgeons [10]. Also, it is the most likely part to injure nerve. The ZESSYS foraminoplasty instrument is inserted via a Kirschner wire in the long thinner cannula of double-cannula, which plays the role of isolation and protection. Precise foraminoplasty under 3D Navigation guidance combined with double-cannula technique protection excludes the exiting nerve root from the working zone of the trephine providing definite neurological safety.

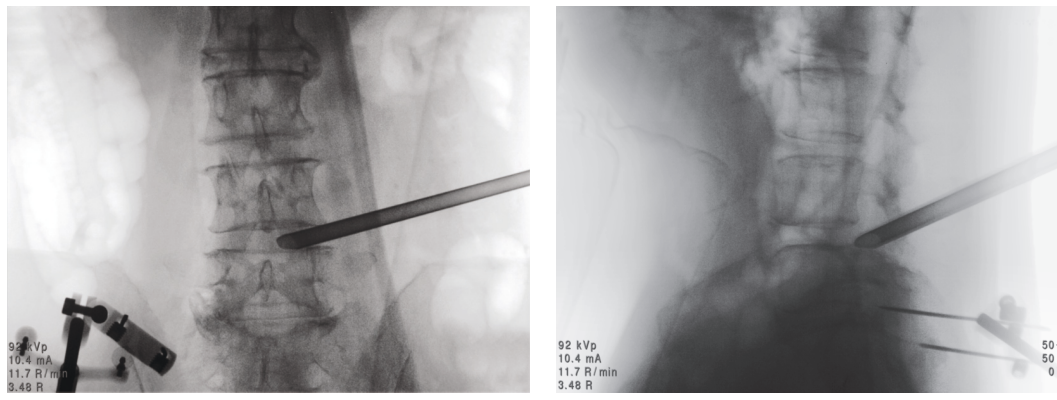
ZESSYS, the targeted foraminoplasty instrument specially designed for navigation procedure, meanwhile offered variable options of facet-cutting amount and adjustable foraminoplasty site. During the procedure of foraminoplasty, trephine was used to move anterior aspect bone of SAP. If driven by hand without any fixation, the trephine was easy to drift. However, in the dual-cannula, the thinner cannula could contain a guide Kirschner wire for fixation




(a) (b)

(c) (d)

Figure 4: The axial (a) and sagittal (b) reconstructed images and anteroposterior (c) and lateral (d) composite images of intraoperative navigation during foraminoplasty.




(a) (b)

Figure 5: The anteroposterior (a) and lateral (b) fluoroscopy views of intraoperative radiograph after the working cannel placed.

and larger cannula for bony abrasion by bone drill/trephine. The Kirschner wires in the smaller tube would be fixed at the posterior aspect of the distal vertebra providing a fixed pivot to avoid accidental instrument sliding during facet-cutting on irregular lateral shape of facet joint. Furthermore, the double-cannula could be rotated by the center of fixed Kirschner wire, and then the larger cannula could be easily docked on the SAP for target foraminoplasty.

The radiation exposure to both patients and medical staff is a great concern in spine surgery [21, 22]. Navigation-assisted fluoroscopy will not prevent exposure to the patient since they must remain in the radiation field during image

acquisition. Fortunately, radiation exposure to patients is limited to the procedure itself. Unless they are undergoing multiple procedures involving fluoroscopy, their risk has been negligible. In a recent experimental study of radiation exposure to the fetus, it was estimated that at least 35 minutes of fluoroscopy would be needed for the induction of radiation related effects [23]. However, the medical staff suffered cumulative radiation exposure during every surgery, especially for the spine surgeons. When comparing radiation exposure experienced by a spine surgeon to other orthopedic subspecialties, a spine surgeon sees 50 times the lifetime radiation dose compared to that of a hip surgeon [24]. The authors in [25] have demonstrated that, in the case of the O-arm system, there exists little to no scatter at distances beyond approximately 4 m. Therefore, technically, there is minimal to no radiation exposure to the surgeons, which reduces the harm to medical staff.

## 5. Conclusions

The study indicated that PELD assisted by O-arm navigation is safe, accurate, and efficient for the treatment of lumbar intervertebral disc herniation. It reshaped the learning curve of PELD, reduced the difficulty of surgery, and minimized radiation exposure to surgeons.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

Shengxiang Ao and Junlong Wu contributed equally to this work.

## Acknowledgments

The authors thank Yifei Chen, Center of Cognition and Brain Science, Beijing Institute of Medical Sciences, for the help of statistics. This research was supported by the clinical research project of the Second Affiliated Hospital of Army Medical University (Grant No. 2015YLC22).

## References

[1] S. S. Virk and E. Yu, "The top 50 articles on minimally invasive spine surgery," *The Spine Journal*, vol. 42, no. 7, pp. 513–519, 2017.

[2] M. R. Rasouli, V. Rahimi-Movaghar, F. Shokraneh, M. Moradi-Lakeh, and R. Chou, "Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation," *Cochrane Database of Systematic Reviews*, vol. 9, Article ID CD010328, 2014.

[3] X. Liu, S. Yuan, Y. Tian et al., "Comparison of percutaneous endoscopic transforaminal discectomy, microendoscopic discectomy, and microdiscectomy for symptomatic lumbar disc herniation: Minimum 2-year follow-up results," *Journal of Neurosurgery: Spine*, vol. 28, no. 3, pp. 317–325, 2018.

[4] W. Ruan, F. Feng, Z. Liu, J. Xie, L. Cai, and A. Ping, "Comparison of percutaneous endoscopic lumbar discectomy versus open lumbar microdiscectomy for lumbar disc herniation: A meta-analysis," *International Journal of Surgery*, vol. 31, pp. 86–92, 2016.

[5] H. Wang, B. Huang, C. Li et al., "Learning curve for percutaneous endoscopic lumbar discectomy depending on the surgeon's training level of minimally invasive spine surgery," *Clinical Neurology and Neurosurgery*, vol. 115, no. 10, pp. 1987–1991, 2013.

[6] S. Ao, J. Wu, W. Zheng, and Y. Zhou, "A novel targeted foraminoplasty device improves the efficacy and safety of foraminoplasty in percutaneous endoscopic lumbar discectomy: preliminary clinical application of 70 cases," *World Neurosurgery*, vol. 115, pp. e263–e271, 2018.

[7] H. S. Kim, F. Yudoyono, B. Paudel et al., "Suprapedicular circumferential opening technique of percutaneous endoscopic transforaminal lumbar discectomy for high grade inferiorly migrated lumbar disc herniation," *BioMed Research International*, vol. 2018, Article ID 5349680, 7 pages, 2018.

[8] J.-S. Kim, S. S. Eun, N. Prada, G. Choi, and S.-H. Lee, "Modified transcorporeal anterior cervical microforaminotomy assisted by O-arm-based navigation: a technical case report," *European Spine Journal*, vol. 20, Supplement 2, no. 2, pp. S147–S152, 2011.

[9] C. Zhang, J. Wu, C. Xu et al., "Minimally invasive full-endoscopic posterior cervical foraminotomy assisted by o-arm-based navigation," *Pain physician*, vol. 21, no. 3, pp. E215–E223, 2018.

[10] M. Schubert and T. Hoogland, "Endoscopic transforaminal nucleotomy with foraminoplasty for lumbar disk herniation," *Operative Orthopädie und Traumatologie*, vol. 17, no. 6, pp. 641–661, 2005.

[11] D. Y. Lee and S.-H. Lee, "Learning curve for percutaneous endoscopic lumbar discectomy," *Neurologia medico-chirurgica*, vol. 48, no. 9, pp. 383–389, 2008.

[12] C. Chaichankul, S. Poopitaya, and W. Tassanawipas, "The effect of learning curve on the results of percutaneous transforaminal endoscopic lumbar discectomy," *Journal of the Medical Association of Thailand*, vol. 95, supplement 10, pp. S206–S212, 2012.

[13] G. Fan, R. Han, X. Gu et al., "Navigation improves the learning curve of transforamimal percutaneous endoscopic lumbar discectomy," *International Orthopaedics*, vol. 41, no. 2, pp. 323–332, 2017.

[14] T. Jentzsch, K. Sprengel, L. Peterer, L. Mica, and C. M. L. Werner, "3D navigation of endoscopic rhizotomy at the lumbar spine," *Journal of Clinical Neuroscience*, vol. 23, pp. 101–105, 2016.

[15] P. A. Laudato, K. Pierzchala, and C. Schizas, "Pedicle screw insertion accuracy using o-arm, robotic guidance, or freehand technique," *The Spine Journal*, vol. 43, no. 6, pp. E373–E378, 2018.

[16] T. Hoogland, K. V. D. Brekel-Dijkstra, M. Schubert, and B. Miklitz, "Endoscopic transforaminal discectomy for recurrent lumbar disc herniation: a prospective, cohort evaluation of 262 consecutive cases," *The Spine Journal*, vol. 33, no. 9, pp. 973–978, 2008.

[17] K.-C. Choi, J.-H. Lee, J.-S. Kim et al., "Unsuccessful percutaneous endoscopic lumbar discectomy: a single-center experience of 10,228 cases," *Neurosurgery*, vol. 76, no. 4, pp. 372–380, 2015.

[18] B. Wang, G. Lü, A. A. Patel, P. Ren, and I. Cheng, "An evaluation of the learning curve for a complex surgical technique: the full endoscopic interlaminar approach for lumbar disc herniations," *The Spine Journal*, vol. 11, no. 2, pp. 122–130, 2011.

[19] H.-T. Hsu, S.-J. Chang, S. S. Yang, and C. L. Chai, "Learning curve of full-endoscopic lumbar discectomy," *European Spine Journal*, vol. 22, no. 4, pp. 727–733, 2013.

[20] S.-S. Ahn, S.-H. Kim, and D.-W. Kim, "Learning curve of percutaneous endoscopic lumbar discectomy based on the period (Early vs. Late) and technique (in-and-out vs. in-and-out-and-in): a retrospective comparative study," *Journal of Korean Neurosurgical Society*, vol. 58, no. 6, pp. 539–546, 2015.

[21] D. Srinivasan, K. D. Than, A. C. Wang et al., "Radiation safety and spine surgery: Systematic review of exposure limits and methods to minimize radiation exposure," *World Neurosurgery*, vol. 82, no. 6, pp. 1337–1343, 2014.

[22] G. Fan, Q. Fu, X. Wu et al., "Patient and operating room personnel radiation exposure in spinal surgery," *The Spine Journal*, vol. 15, no. 4, pp. 797–799, 2015.

[23] N. Theocharopoulos, J. Damilakis, K. Perisinakis, G. Papadokostakis, A. Hadjipavlou, and N. Gourtsoyiannis, "Fluoroscopically assisted surgical treatments of spinal disorders: Conceptus radiation doses and risks," *The Spine Journal*, vol. 31, no. 2, pp. 239–244, 2006.

[24] E. B. Gausden, A. B. Christ, R. Zeldin, J. M. Lane, and M. M. McCarthy, "Tracking cumulative radiation exposure in orthopaedic surgeons and residents," *Journal of Bone and Joint Surgery - American Volume*, vol. 99, no. 15, pp. 1324–1329, 2017.

[25] K. G. Abdullah, F. S. Bishop, D. Lubelski, M. P. Steinmetz, E. C. Benzel, and T. E. Mroz, "Radiation exposure to the spine surgeon in lumbar and thoracolumbar fusions with the use of an intraoperative computed tomographic 3-dimensional imaging system," *The Spine Journal*, vol. 37, no. 17, pp. E1074–E1078, 2012.

Hindawi
BioMed Research International
Volume 2019, Article ID 9528102, 8 pages
https://doi.org/10.1155/2019/9528102

*Clinical Study*

# The Usefulness of Percutaneous Endoscopic Technique in Multifocal Lumbar Pathology

**Chul-Woo Lee and Kang-Jun Yoon**

*Department of Neurosurgery, St. Peter's Hospital, Seoul 135-809, Republic of Korea*

Correspondence should be addressed to Chul-Woo Lee; mannitol240@gmail.com

Received 16 August 2018; Accepted 18 December 2018; Published 3 January 2019

Guest Editor: Hyeun S. Kim



*Introduction.* The multifocal lumbar pathology including disc herniation and stenosis in the spinal canal or foramen has been considered the most difficult to approach surgically. It often requires mandatory dual approaches and/or fusion techniques. Traditional percutaneous endoscopic lumbar transforaminal and interlaminar approach has been focused on unifocal disc herniation. However, the development of endoscopic spinal instruments and surgical technique has broadened surgical indication and therapeutic boundary in endoscopic spine surgery. *Cases Presentation.* The authors present outcomes of four patients with multilumbar pathology including highly inferior migrated disc combined with lateral recess stenosis, multifocal disc herniation, bilateral disc herniations in spinal canal and foraminal disc herniation combined with central canal stenosis. They were successfully treated by percutaneous uniportal full endoscopic approach with single incision. *Conclusion.* Percutaneous endoscopic spine surgery is a safe and effective tool to figure out multilumbar pathology in a minimal invasive way.

## 1. Introduction

Traditional percutaneous endoscopic lumbar transforaminal and interlaminar approach has been focused on unifocal disc herniation [1–5]. However, the evolution of endoscopic instruments such as drills and punches and the development of surgical technique have broadened surgical indication and therapeutic boundary in endoscopic spine surgery. Lumbar spinal diseases ranging from simple contained disc to complicated cases such as highly migrated disc herniation and other pathology combined with bony degeneration to produce foraminal and canal stenosis can now be operated fully with endoscope using various accesses and techniques [6–13].

The multifocal lumbar pathology including disc herniation and stenosis in the spinal canal or foramen has been considered the most difficult to approach surgically. It often requires mandatory dual approaches and/or fusion techniques. Endoscopic surgical techniques may reduce the need for these more invasive methods. A uniportal full endoscopic approach with single incision can satisfactorily resolve these challenging cases. Here we present outcomes of four patients with multipathologies in the lumbar spine who were successfully managed with a single endoscopic approach.

## 2. Cases Presentation

*2.1. Case 1.* A 60-year-old woman suffered from left gluteal, thigh, and calf pain along the L5 dermatome for two months. Manual muscle test for the left great-toe dorsiflexion and the ankle dorsiflexion showed grades III and IV, respectively. She also suffered from neurogenic intermittent claudication symptom (50 m). Magnetic resonance (MR) images demonstrated disc extrusion and downmigrated disc herniation combined with spinal canal and lateral recess stenosis at L4–5 level (Figure 1(a)). Although she underwent a steroid epidural injection with medications, the pain did not improve. Foraminoplastic percutaneous endoscopic lumbar discectomy (PELD) using reamers was performed in the prone position under local anesthesia [6]. The patient communicated with the surgeon during the entire procedure. The blue stained inferior migrated ruptured disc was seen beyond the partially resected superior articular process (SAP)

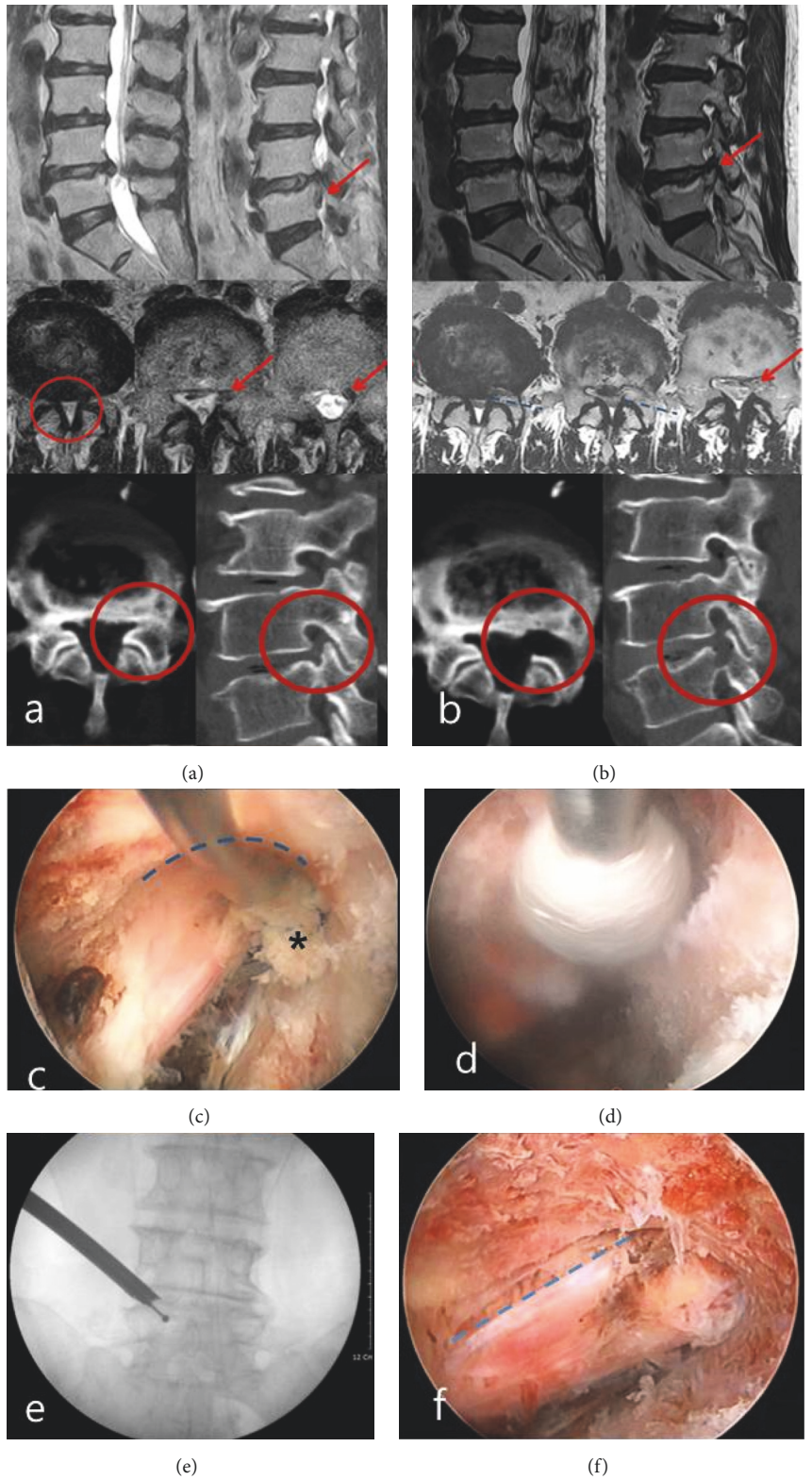



Figure 1: Highly inferior migrated disc combined with spinal canal and lateral recess stenosis. (a) Preoperative sagittal and axial T2-weight MRI showing ruptured right side inferior migrated disc material combined with central canal and lateral recess stenosis at L4-5. Red arrow: inferior migrated disc; red circle: stenotic region in spinal canal and lateral recess. (b) Postoperative axial and sagittal T2-weight MRI and CT showing the removed inferior migrated disc materials and decompression of lateral recess at L4-5. Red arrow: decompressed area by removal of inferior migrated disc materials; red circle: decompressed area from preoperative stenosis; blue dotted line: resected plane of superior articular process. (c) Part of inferior migrated disc materials was seen by retraction of flexible probe. Dotted blue line: resected ventral plane of superior articular process by reamers; asterisk: tip of inferior migrated disc materials. (d) Further decompression of lateral recess was performed by drilling. (e) Intraoperative C-Arm image showing the location of drill tip during lateral recess decompression. (f) Totally decompressed traversing root was seen at the end stage of operation blue dotted line: dorsal margin of the traversing root.

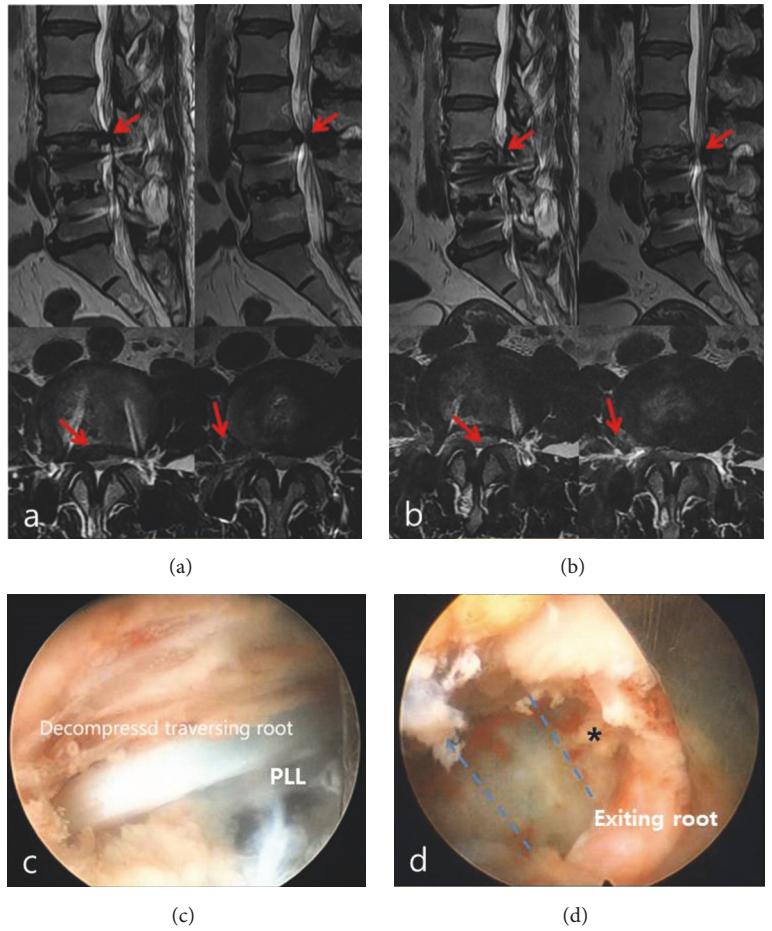



Figure 2: Single level multi-focal, paracentral, and far-lateral lumbar disc herniations. (a) Preoperative sagittal and axial T2-weight MRI showing multifocal, paracentral, and far-lateral lumbar disc herniations at L3-4. Red arrows: paracentral and extraforaminal disc herniation. (b) Postoperative axial and sagittal T2-weight MRI showing the removed paracentral and far-lateral lumbar disc herniations at L3-4. Red arrows: decompressed area by removal of paracentral and extraforaminal disc herniation. (c) Paracentrally herniated disc materials were removed and decompressed traversing root was seen. PLL: posterior longitudinal ligament. (d) Change of working cannula angle showing the foraminal area. Asterisk: tip of remnant extraforaminal disc; dotted blue line: disc level.

(Figure 1(e)). The herniated disc and fibrotic scar tissues were released and removed using endoscopic forceps and radiofrequency. The ventral portion of decompressed traversing root was confirmed. Additional removal of SAP was performed. Part of the L5 upper end plate around the lateral recess was drilled out. The ligament flavum was also removed, reaching the spinal canal by an endoscopic punch (Figures 1(c) and 1(d)). This resulted in the whole traversing root being exposed (Figure 1(f)). After the operation, her visual analogue scale (VAS) scores of the back and leg pain improved from 6 and 8, respectively, to 2 and 1, respectively. Postoperative MR and CT images (Figure 1(b)) showed complete removal of the ruptured disc fragment and decompressed lateral recess area. The patient was discharged on the day after PELD.

*2.2. Case 2.* A 50-year-old woman visited the clinic because of severe right-leg radiating pain along the L2 and L3 dermatome. She has a history of fusion surgery five years ago. MR images revealed intracanal and extraforaminal multifocal soft disc herniation at the L3-4 level (Figure 2(a)). Although she underwent nerve-root block at L3 and L4, the pain sustained. PELD with foraminoplasty using reamers was performed. After removal of the herniated disc in the paracentral area (Figure 2(c)), working cannula was slightly withdrawn and reapproached with a stiff angle in order to confirm compressed exiting root. Another stained ruptured disc fragment was found at the axilla area of exiting root by a gentle circular twisting motion of working cannula (Figure 2(d)). It was removed by forceps with caution to avoid the exiting root injury by excessive manipulation. Postoperatively, the patient's preoperative leg pain was resolved without complications. Back and leg pain VAS scores decreased from 6 and 7 preoperatively to 3 and 2 postoperatively. MR images showed successful simultaneous removal of paracentral and extraforaminal double disc herniations (Figure 2(b)).

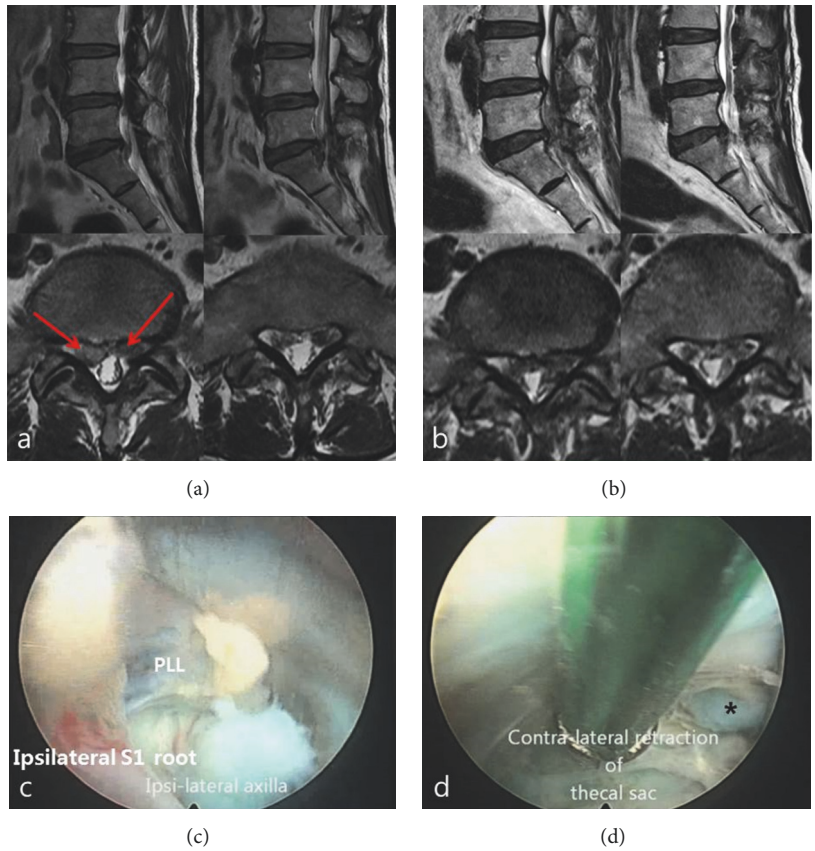



Figure 3: Bilateral disc herniations on L5-S1. (a) Preoperative sagittal and axial T2-weight MRI showing thecal sac compression due to L5–S1 bilateral disc herniations. Red arrows: bilateral disc herniations compressing thecal sac. (b) Postoperative axial and sagittal T2-weight MRI showing decompressed thecal sac and bilateral S1 root by removal of bilateral disc herniation at L5-S1. (c) Ruptured disc material seen at ipsilateral axilla area of S1. PLL: posterior longitudinal ligament. (d) Tip of contralateral ruptured disc was exposed by retraction of thecal sac. Asterisk: tip of the ruptured disc from contralateral epidural space.

*2.3. Case 3.* A 58-year-old woman presented with acute onset left-leg radiating pain. She also had constant right-leg radiating leg pain for one year. Bilateral straight leg raise test was positive. MR images showed L5–S1 bilateral herniated disc (Figure 3(a)). Despite conservative treatment with physical therapy and interventional pain management, the patient's symptom did not improve. A working cannula was placed on the interlaminar space via a 0.7 mm skin incision under epidural anesthesia. The ligamentum flavum was then split by the probe in the middle part on the ipsilateral side. A working cannula with endoscope was subsequently introduced into the epidural space through the split ligamentum flavum and the dura sac and nerve root were exposed. After gentle retraction of the ipsilateral S1 root, epidural dissection by various endoscopic instruments, a working channel was inserted into the axillary area of S1 root. Sequestrated disk materials located on the ipsilateral side were found and removed with forceps (Figure 3(c)). The central portion of the annulus and the posterior longitudinal ligament (PLL) located at the center were cleared and identified to expose the contralateral side. Further exposure of contralateral epidural space by retraction of thecal sac was followed. Another protruded disc was identified under thecal sac on the contralateral side (Figure 3(d)). Probes were moved to the site to remove and puncture organized disc materials. Forceps were used to remove the contralateral ruptured disc. The working cannula was withdrawn and reapproached over the thecal sac to observe the contralateral side. Decompressed contralateral the traversing nerve root was confirmed. Postoperatively, the patient showed no symptoms radiating to the legs. There were no deficits on neurological examination. Postoperative MR images revealed that preoperative herniated discs were successfully removed bilaterally (Figure 3(b)).

*2.4. Case 4.* A 77-year-old woman presented with complaints of radicular pain in the right gluteal region and anterolateral aspect of her thigh and leg for three months. She was also suffering from neurogenic claudication symptom. She could not walk more than 50 meters continuously. MR images of the lumbar spine revealed extraforaminal disc combined with central canal stenosis on L4-5 (Figure 4(a)). A plain radiograph showed a minimal listhesis. The L4-5 segment was stable. The patient was operated under epidural anesthesia in a prone position on a spinal frame. The skin incision was marked lateral to spinous process contralateral to the side of the foramen to be decompressed and directed towards the

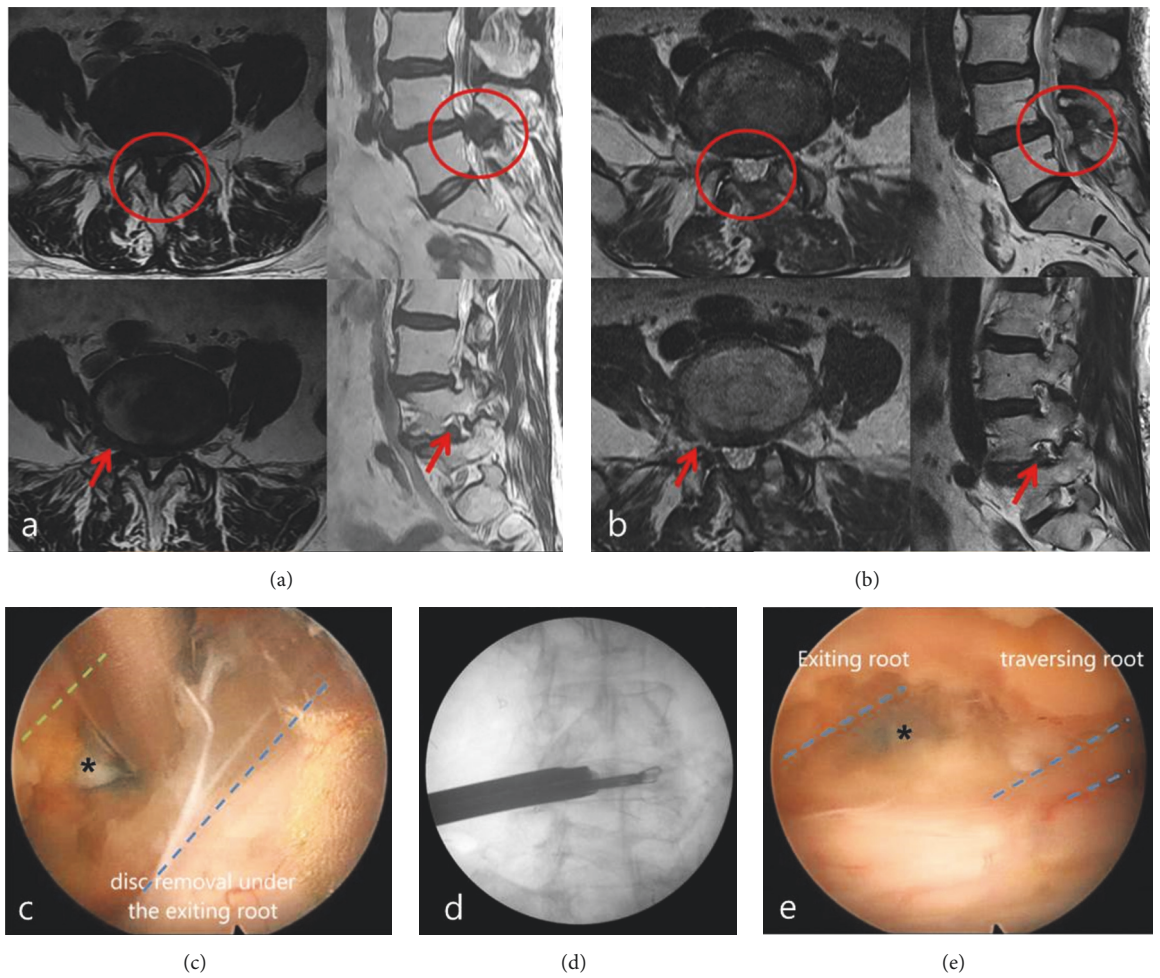



Figure 4: Extraforaminal disc herniation combined with central canal stenosis. (a) Preoperative sagittal and axial T2-weight MRI showing foraminal disc herniation combined with central canal stenosis. Red arrows: extraforaminal disc; red circle: stenotic region in spinal canal. (b) Postoperative axial and sagittal T2-weight MRI showing decompressed thecal sac and contralateral L4 root after removal of extraforaminal disc herniation at L4-5. Red arrows: decompressed area by removal of extraforaminal disc; red circle: enlarged spinal canal from preoperative stenosis. (c) Contralateral extraforaminal disc seen under the contralateral exiting root. Asterisk: ruptured extraforaminal disc; green dotted line: inferior margin of contralateral exiting root; blue dotted line: contralateral margin of thecal sac. (d) Intraoperative C-Arm image showing the location of forceps grasping protruded contralateral extraforaminal disc materials. (e) Decompressed both contralateral exiting and traversing root. Asterisk: removed site of extraforaminal disc. Blue dotted line: contralateral exiting and traversing root.

side of the stenosis. A 12 mm working cannula was placed on the lower margin of L4 ipsilateral spinolamina junction initially and an endoscope was inserted. Laminotomy was performed with high-speed endoscopic drills. Thinned-out lamina was adequately removed with an endoscopic Kerrison rongeur. The base of the spinal process was then removed to obtain a clear view of the contralateral lateral recess and the foramen. The ligamentum flavum was initially preserved to protect the dura. After completion of bony resections, the ligamentum flavum was removed piecemeal starting from the midline. Lateral margin of thecal sac was exposed. Gentle retraction of the contralateral thecal sac from the lateral to medial direction revealed a protruded contralateral side extraforaminal disc which was removed by endoscopic forceps (Figures 4(c) and 4(d)). Afterward, the opposite lateral recess and the foramen were further decompressed by removing the ligamentum flavum, drilling osteophytes, clearing all disc fragments, and undercutting the medial facet. Finally, successfully decompressed contralateral exiting and traversing nerve root was confirmed (Figure 4(e)). After the operation, her VAS scores of the back and leg pain improved from 5 and 8 preoperatively to 2 and 2, respectively. Postoperative MR images showed complete removal of ruptured extraforaminal disc fragments and decompressed spinal canal (Figure 4(b)).

## 3. Discussion

Spinal disease is the natural aging process. Such degenerative change induces lumbar spinal disease which has a variable

spectrum ranging from simple disc herniation to severe degenerative spondylosis such as listhesis, stenosis, and kyphoscoliotic deformity. Among those diseases, a simple single lumbar pathology could be mostly figured out by a single therapeutic modality and approach. However, multifocal or combined different type of pathology in the lumbar spine would need more invasive surgical methods such as two staged dual approaches or fusion technique in order to solve such different and complex combined pathologies.

We presented outcomes of four patients with multilumbar pathology who were successfully treated by a single endoscopic approach. If endoscopy was not used, more invasive treatments would have been needed for these cases.

Endoscopic operations such as arthroscopy and laparoscopy are becoming standard operations nowadays. Lumbar spinal diseases ranging from simple contained disc to complicated cases such as highly migrated disc herniation and other pathology combined with bony degeneration to produce foraminal and canal stenosis can now be treated with full-endoscopic surgery using various accesses and techniques [6–13]. Many authors have reported advantages of percutaneous endoscopic surgery compared to previous traditional surgery. These advantages include minimal injury to spinal segmental structures including muscle, facet joint and dorsal ramus, short hospital stay, early return to regular activity, and patient's high satisfaction [7, 14, 15]. Numerous merits of percutaneous endoscopic surgery were also revealed distinctly in the current series. Traditional spinal surgery needs massive paravertebral muscle dissection and two staged operations in order to acquire enough operative fields to cover different and distant dual pathologies like current cases. However, percutaneous endoscopic approach achieved the same goal with only 7-12 mm single tiny skin portal and minimized handling of endoscopic instruments. All patients were discharged within one or two days after the operation. Postoperatively, patients immediately resumed their regular activities of daily living. They were able to return to clerical forms of work within seven days. Such postoperative course might not be observed if we operated with traditional surgical methods to treat these cases. Successful clinical results in these multilumbar pathology cases mentioned above might be due to some unique characteristics of endoscopic spine surgery.

The lens located on the tip of the tube-shaped endoscope to see the operative field can be referred to as the "operative eye". The "operative eye" can be placed very close to the operative target directly passing anatomical structures in endoscopic spine surgery. Unlike traditional bare-eye or microscopic surgery, it is not necessary to destroy much of normal structures to access the target pathology and secure operative corridor to see the operative field. In the first case, traditional laminotomy techniques could be used for lateral recess decompression with removal of the highly inferior migrated disc herniation. However, these surgical options could not avoid injury to posterior segmental structures by dissection of the paravertebral muscle and the partial removal of the lamina and facet joint. Target oriented direct accessibility in endoscopic surgery mentioned above helped us minimize the operative iatrogenic injury and save normal segmental spinal structures in current cases. It led to good clinical outcome such as patient's fast recovery and early return to regular activity despite their multilumbar pathology.

Operative instruments used in endoscopic spine surgery are relatively small compared to near anatomical spinal structures. The "operative eye" on the tip of such a small endoscope can navigate around the target with minimal pivoting movement of the endoscope via an initial single skin portal. Moreover, recent development of the endoscopic drill system has expanded surgical boundary where the endoscope could not previously approach or move around. Such characteristics of endoscopic spinal surgery provided probing and small sized working spot, enabling authors to explore a relatively large operative field and manage two different distant targets simultaneously in current cases. The second and third cases showed navigability of the spinal endoscope that helped us treat the multilumbar pathology successfully.

Variability of endoscopic surgical angle is another distinct feature of spinal endoscope regarding surgical success in current series. Only a slight withdrawal of endoscope after the initial approach can give surgeons the opportunity to reapproach, change the working trajectory, and manipulate structures around different surgical targets without needing another skin incision or different secondary surgical corridor as shown in the second and third cases. The optical angle of a spinal endoscope is 15-20 degrees. With rotation or tilting of the endoscope, an endoscopic operative angle can provide a more variable surgical view and working trajectory. It helps the surgeon reach farther targets that could not be reached by microscope. It also helps surgeons explore hidden areas easily without destroying normal anatomical structures needed to be removed to observe the target with traditional surgical methods. The fourth case was a good example of endoscopic surgery which was performed by a precise, targeted approach via the least invasive surgical route using the endoscopic angled and long-distance visibility. Instead of using dual approach for both spinal canal decompression and removal of extraforaminal disc herniation or the fusion method with wide decompression, endoscopic contralateral approach was chosen. It achieved the same surgical goal. Optimized oblique sublaminoplasty for canal decompression and removal of far lateral disc from contralateral side were possible due to the long distance of the visibility, natural optical angle, and tilting maneuver of the spinal endoscope.

In the current case series, satisfactory clinical results were acquired from all patients by using minimally invasive endoscopic procedure. However, percutaneous endoscopic spine surgery is not omnipotent. Although all cases in the current series were successfully resolved by a single endoscopic approach, these techniques cannot be applied to all forms of lumbar spinal diseases, especially for those with severe lumbar spinal stenosis with spondylolisthesis or instability. It should be performed carefully for selected patients. Percutaneous endoscopic spine surgery has a steep learning curve as previously reported by many authors [7, 16–19]. All cases in the current series were operated by a single surgeon (C.W. Lee) who has performed over 2,000 cases of

endoscopic spine surgeries. Lack of clinical experience in endoscopic spine surgery could be the major cause of surgical failure and undesirable operative complications [17, 20–22]. Furthermore, complex and difficult cases with multilumbar pathology would have much higher operative failure risk. Endoscopic surgeons who are considering the use of endoscopic technique in treating multilumbar pathology are recommended to have abundant experience in endoscopic surgery. They also should be familiar with the usage of various endoscopic instruments (such as endoscopic drills and reamers) and working cannula handling (such as withdrawal, tilting, and rotation).

## 4. Conclusions

Percutaneous endoscopic spine surgery is a safe and effective tool to resolve multilumbar pathology in a minimal invasive way. It can be an alternative to traditional surgical methods by minimizing iatrogenic injury to normal segmental structures and providing good clinical outcome to the patients.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest relevant to this study.

## References

[1] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach," *Journal of Neurosurgery: Spine*, vol. 6, no. 6, pp. 521–530, 2007.

[2] G. Choi, S.-H. Lee, A. Bhanot, P. P. Raiturker, and Y. S. Chae, "Percutaneous endoscopic discectomy for extraforaminal lumbar disc herniations: extraforaminal targeted fragmentectomy technique using working channel endoscope," *The Spine Journal*, vol. 32, no. 2, pp. E93–E99, 2007.

[3] H. S. Kim, C. I. Ju, S. W. Kim, and J. G. Kim, "Endoscopic transforaminal suprapedicular approach in high grade inferior migrated lumbar disc herniation," *Journal of Korean Neurosurgical Society*, vol. 45, no. 2, pp. 67–73, 2009.

[4] S.-H. Lee and H. S. Kang, "Percutaneous endoscopic laser annuloplasty for discogenic low back pain," *World Neurosurgery*, vol. 73, no. 3, pp. 198–206, 2010.

[5] C. H. Kim and C. K. Chung, "Endoscopic interlaminar lumbar discectomy with splitting of the ligament flavum under visual control," *Journal of Spinal Disorders & Techniques*, vol. 25, no. 4, pp. 210–217, 2012.

[6] C.-W. Lee, K.-J. Yoon, S.-S. Ha, and J.-K. Kang, "Foraminoplastic superior vertebral notch approach with reamers in percutaneous endoscopic lumbar discectomy: technical note and clinical outcome in limited indications of percutaneous endoscopic lumbar discectomy," *Journal of Korean Neurosurgical Society*, vol. 59, no. 2, pp. 172–181, 2016.

[7] C.-W. Lee, K.-J. Yoon, and J.-H. Jun, "Percutaneous Endoscopic Laminotomy with Flavectomy by Uniportal, Unilateral Approach for the Lumbar Canal or Lateral Recess Stenosis," *World Neurosurgery*, 2018.

[8] Y. Ahn, H.-K. Oh, H. Kim, S.-H. Lee, and H.-N. Lee, "Percutaneous endoscopic lumbar foraminotomy: An advanced surgical technique and clinical outcomes," *Neurosurgery*, vol. 75, no. 2, pp. 124–132, 2014.

[9] C. Lee, M. Choi, D. S. Ryu et al., "Efficacy and Safety of Full-endoscopic Decompression via Interlaminar Approach for Central or Lateral Recess Spinal Stenosis of the Lumbar Spine," *The Spine Journal*, vol. 43, no. 24, pp. 1756–1764, 2018.

[10] K.-C. Choi, D. C. Lee, H.-K. Shim, S.-H. Shin, and C.-K. Park, "A Strategy of Percutaneous Endoscopic Lumbar Discectomy for Migrated Disc Herniation," *World Neurosurgery*, vol. 99, pp. 259–266, 2017.

[11] H. S. Kim, R. Patel, B. Paudel et al., "Early Outcomes of Endoscopic Contralateral Foraminal and Lateral Recess Decompression via an Interlaminar Approach in Patients with Unilateral Radiculopathy from Unilateral Foraminal Stenosis," *World Neurosurgery*, vol. 108, pp. 763–773, 2017.

[12] J. H. Hwang, W. M. Park, and C. W. Park, "Contralateral Interlaminar Keyhole Percutaneous Endoscopic Lumbar Surgery in Patients with Unilateral Radiculopathy," *World Neurosurgery*, vol. 101, pp. 33–41, 2017.

[13] G. Choi, S.-H. Lee, P. Lokhande et al., "Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope," *The Spine Journal*, vol. 33, no. 15, pp. E508–E515, 2008.

[14] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: A prospective, randomized, controlled study - Clinical article," *Journal of Neurosurgery: Spine*, vol. 10, no. 5, pp. 476–485, 2009.

[15] L. Cong, Y. Zhu, and G. Tu, "A meta-analysis of endoscopic discectomy versus open discectomy for symptomatic lumbar disk herniation," *European Spine Journal*, vol. 25, no. 1, pp. 134–143, 2016.

[16] E. C. Benzel and R. D. Orr, "A steep learning curve is a good thing!," *The Spine Journal*, vol. 11, no. 2, pp. 131-132, 2011.

[17] K. Sairyo, T. Sakai, K. Higashino, M. Inoue, N. Yasui, and A. Dezawa, "Complications of endoscopic lumbar decompression surgery," *Minimally Invasive Neurosurgery*, vol. 53, no. 4, pp. 175–178, 2010.

[18] D. Y. Lee and S.-H. Lee, "Learning curve for percutaneous endoscopic lumbar discectomy," *Neurologia medico-chirurgica*, vol. 48, no. 9, pp. 383–389, 2008.

[19] B. Wang, G. Lü, A. A. Patel, P. Ren, and I. Cheng, "An evaluation of the learning curve for a complex surgical technique: the full endoscopic interlaminar approach for lumbar disc herniations," *The Spine Journal*, vol. 11, no. 2, pp. 122–130, 2011.

[20] Y. Ahn, "Transforaminal percutaneous endoscopic lumbar discectomy: Technical tips to prevent complications," *Expert Review of Medical Devices*, vol. 9, no. 4, pp. 361–366, 2012.

[21] G. Anichini, A. Landi, F. Caporlingua et al., "Lumbar Endoscopic Microdiscectomy: Where Are We Now? An Updated Literature Review Focused on Clinical Outcome, Complications, and Rate of Recurrence," *BioMed Research International*, vol. 2015, Article ID 417801, 2015.

[22] C. Birkenmaier, M. Komp, H. F. Leu, B. Wegener, and S. Ruetten, "The current state of endoscopic disc surgery: review

of controlled studies comparing full-endoscopic procedures for disc herniations to standard procedures," *Pain Physician*, vol. 16, no. 4, pp. 335–344, 2013.

Hindawi
BioMed Research International
Volume 2018, Article ID 4749560, 6 pages
https://doi.org/10.1155/2018/4749560

*Clinical Study*

# Working Cannula-Based Endoscopic Foraminoplasty: A Technical Note

**Suxi Gu,[1] Kedong Hou,[2] Wei Jian,[3] Jianwei Du,[4] Songhua Xiao ,[1] and Xifeng Zhang [5]**

[1]*Orthopedic Department, Beijing Tsinghua Changgung Hospital, School of Clinical Medicine, Tsinghua University, Beijing 102248, China*
[2]*Orthopedic Department, Beijing Friendship Hospital Pinggu Campus, Capital Medical University, Beijing 101200, China*
[3]*Orthopedic Department, Beijing PLA 309 Hospital, Beijing 100091, China*
[4]*Orthopedic Department, Yangzhou No. 1 People's Hospital, Yangzhou, Jiangsu Province 225001, China*
[5]*Orthopedic Department, PLA General Hospital, Beijing 100853, China*

Correspondence should be addressed to Songhua Xiao; xiaosonghua301@gmail.com and Xifeng Zhang; 656780949@qq.com

Received 3 September 2018; Accepted 21 November 2018; Published 23 December 2018

Guest Editor: H. Michael Mayer



*Purpose*. Percutaneous endoscopic lumbar discectomy (PELD) is a minimally invasive disc surgery that can be performed under local anesthesia and requires only an eight-mm skin incision. For the patients with lumbar foraminal stenosis, the migrated disc is difficult to remove with a simple transforaminal approach. In such cases, the foraminoplasty techniques can be used. However, obtaining efficient foramen enlargement while minimizing radiation exposure and protecting the nerves can be challenging. *Methods*. In this study, we propose a new technique called the Kiss-Hug maneuver. Under endoscopic viewing, we used the bevel tip of a working cannula as a bone reamer to enlarge the foramen. This allowed us to efficiently enlarge the lumbar foramen endoscopically without the redundancy and complications associated with reamers or trephines. *Results*. Details of the four steps of the Kiss-Hug maneuver are reported along with adverse events. The advantages of this new technique include minimizing radiation exposure to both the surgeon and the patient and decreasing the overall operation time. *Conclusion*. The endoscopic Kiss-Hug maneuver is a useful and reliable foraminoplasty technique that can enhance the efficiency of foraminoplasty while ensuring patient safety and reducing radiation exposure.

## 1. Introduction

Although open lumbar discectomy is the gold standard surgical technique for lumbar disc herniation, iatrogenic damage on the facet joints and other paraspinal structures along with reduced disc height, segmental instability, and retrolisthesis may become a problem [1, 2]. Therefore, percutaneous endoscopic lumbar discectomy (PELD)'s transforaminal approach is gaining recognition. It has many advantages including reduced paraspinal muscle trauma, minimal postoperative instability, and a smaller surgical wound [3–5]. Transforaminal approach provides easy access to the entirety of the bulging or calcified disc, the inferior facet, and the front of the laminae [6, 7]. The enlargement of the target foramina provides direct access to the lateral foraminal canal and direct visualization of the superior face, the main culprit in lateral spinal canal [7–9].

In patients with foraminal bony stenosis, osteophytes on the substantial superior articular process (SAP) are challenging to remove. Before the operation, patients get a prone position on a radiolucent operating table. Under fluoroscopic guidance, an 18-G needle is inserted. The target position of the needle tip just prior to puncture of the disc is on the posterior vertebral body line on the lateral C-arm view, and on the medial pedicular line on the anteroposterior view. This should correspond to the safe triangle in the axillary area between the exiting and traversing nerve root. In patients with disc fragment migrations, the ideal needle position is difficult to achieve [10–13]. Foraminoplastic procedures, such as removal of SAP osteophytes to widen the lumbar foramen

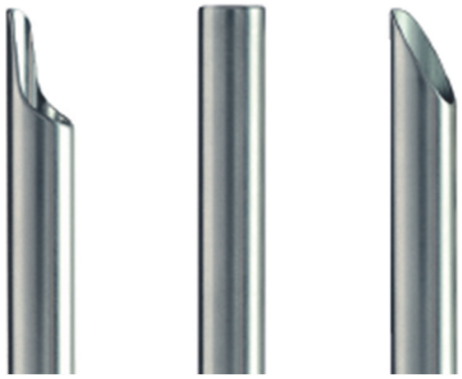


Figure 1: Schematic designs of the working cannula tip. We use a working cannula with the bevel tip (first tip on the right) in the Kiss-Hug procedure.

and removal of parts of the facet and ligamentous tissue surrounding the foramen, are sometimes required to allow the endoscope to enter [7, 10–15]. Multiple studies [7, 9] have indicated that medial access to Kambin's triangle by foraminoplasty provides safer access to the intraforaminal space and makes it possible to prevent exiting nerve injury.

Technically, bone reamers or trephines can quickly cut off hypertrophied SAP or osteophytes [7]. However, as blind techniques, these tools have inherent disadvantages. C-arm-guided foraminoplasty may cause unintended multifluoroscopic exposure, inadequate bone removal, bleeding, significant bony structure removal causing lumbar instability, and even sensitive neural damage [16–20]. To address these concerns, specialized tools for endoscopic foraminoplasty have been developed, such as endoscopic drills, high-speed diamond and articulated burrs, punches, forceps, osteotomes, and the straight- and side-firing Holmium-YAG laser [15, 21]. Unfortunately, these techniques can be less efficient and more time-consuming in cases of severe bony stenosis. Therefore, a more efficient endoscopic method to enlarge the stenotic foramen is needed.

We propose a Kiss-Hug maneuver to efficiently and safely decompress foraminal stenosis, utilizing one of the fundamental tools in the PELD procedure: the working cannula. This technique maximizes the effectiveness of endoscopic decompression while ensuring patient and surgeon safety. In this endoscopic foraminoplasty maneuver, the bevel tip of the working cannula is used as a bone reamer to undercut the SAP without the need for any other specific instrumentation.

## 2. Technical Note

The working cannula is the only equipment required for the Kiss-Hug technique. Although working cannulas are available in different outer diameters, working lengths, and tip configurations, we chose the working cannula with a bevel (distal oblique) tip to minimize the occupying effect of the surgical equipment [Figure 1]. Because the normal vertical and transverse dimension of the lumbar foramen is only 12–19 mm and 12–14 mm, respectively, any space-occupying pathology or instruments can contribute to the existing foramen stenosis and lead to severe nerve impingement [22].

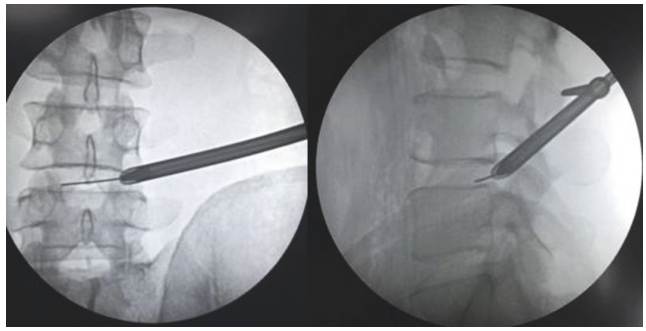


Figure 2: The ideal position of the bevel tip in the working cannula under fluoroscopic anterior posterior view (A) and lateral view (B).

A detailed description of a PELD procedure using the Kiss-Hug maneuver is provided as follows. The procedure begins by advancing the working cannula down to the foramen, following the tapered obturator engaged into the foramen. Before introducing endoscopy, the position of the working cannula should be checked under fluoroscopy. The surgeon must ensure that the tip of the working cannula has not advanced beyond the medial-pedicle line in the anterior posterior view and touches the ventral side of SAP in the lateral view [Figure 2]. The tip of the working cannula should anchor between the SAP and the posterior wall of the caudal vertebra or disc (depends on varies anatomy, away from exiting nerve root, touching the upper surface of caudal pedicle) through the foramen [Figure 3(a)]. At this point, the surgeon should confirm that the bevel tip is facing upward and dorsally, so that the tip fits perfectly into the space and is firmly secured on the ventral side of the SAP. Therefore, the working cannula could gently *kiss* the SAP. This position allows the next step in the maneuver to occur without any slipping or shifting.

After the working cannula is anchored in the foramen, the endoscope is introduced through the cannula. A thorough endoscopic exploration of the foraminal space is performed using a bipolar coagulator. The thickened ventral parts of the facet capsule are removed until the ventral part of the SAP is visualized. Once the location and morphology of the osteophyte has been identified, the surgeon can begin the hug maneuver [Figure 3(b)]. Holding the rear-handle, the surgeon rotates the working cannula, applying a moderate amount of force and constant endoscopic control, as if he is *hugging* the osteophyte.

Typically, the surgeon will use a left-handed fingertip grip on the endoscopy to control the direction of the working cannula and to provide constant direct endoscopic viewing [Figure 5]. Using the right hand to hold the rear-handle, the surgeon can rotate the working cannula and apply the shaving force axially, but not vertically. The blunt edge (about one mm thickness) of the bevel tip works as a bone-cutting blade, and the endoscopy itself works as the rotational axis. Under the twisting or rotating movement of the working cannula, the ventral portion of the osteophyte SAP can be shaved into pieces by the bevel tip. The bone chips can be removed along with the endoscopy from the working cannula. After this step, the bevel tip can be pressed onto the SAP again,

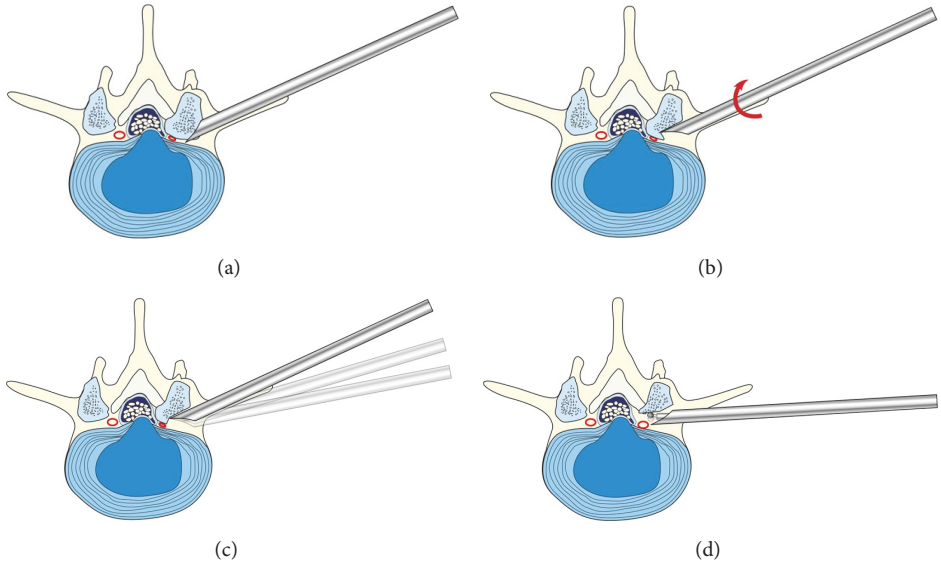



Figure 3: (a) Schematic of the Kiss step: the tip of the working cannula should anchor between the superior articular process (SAP) and the posterior wall of the disc or distal vertebra through the foramen. The bevel side should face upward and dorsally, so that the bevel tip can fit perfectly and securely on the ventral-lateral side of the SAP. (b) Schematic of the Hug step: after identifying the location and morphology of the osteophyte, the surgeon rotates the working cannula to shave off the osteophyte on the superior articular process (SAP), utilizing the bevel tip in a piecemeal fashion. The surgeon must ensure that the working cannula does not advance too far into the spinal canal and that the exiting nerve root is kept outside the protective working cannula. (c) Schematic of the Tilt step: the working cannula can be tilted upward, downward, or leveled to address different pathological requirements until sufficient foramen enlargement has been achieved. The exiting nerve root is particularly vulnerable during this step. Excessive manipulation of the working cannula can cause pressure on the dorsal root ganglion, leading to severe intraoperative pain and postoperative dysesthesia. (d) Schematic of the Finishing step: after shaving off the majority of the osteophyte using Kiss-Hug maneuvers, the opening of the foramen window continues. If necessary, other endoscopic tools such as articulate burrs and side-firing lasers could be used to further remove remnant osseous fragments and thickened ligamentous materials.

and additional Kiss-Hug maneuvers can be performed until enough foraminoplasty has been achieved. This maneuver actually poses a lot shear stress to the bevel tip that may lead to damage of the working cannula. Therefore, the extra combination usage of electrical articulated burrs might be helpful.

For better bone cutting and thorough lumbar foramen enlargement, the elasticity of the muscle tissue and the mobility of the lumbar skin can be used to change the positions and directions of the foraminoplasty [Figure 3(c)]. By holding the endoscopy as a direction-controller and using the cannula's bevel tip as a fulcrum, the surgeon can adjust the trajectory inclination of the working cannula [15].

Once the target foramen has been adequately enlarged [Figure 4], the rest of the procedure is not different from the conventional technique. Remnant osseous fragments and thickened ligamentous material can be removed using endoscopic forceps, articulating burrs, and coagulators until the epidural space and the dura are visualized [Figure 3(d)]. Finally, the surgeon can completely remove the migrated or sequestered discs.

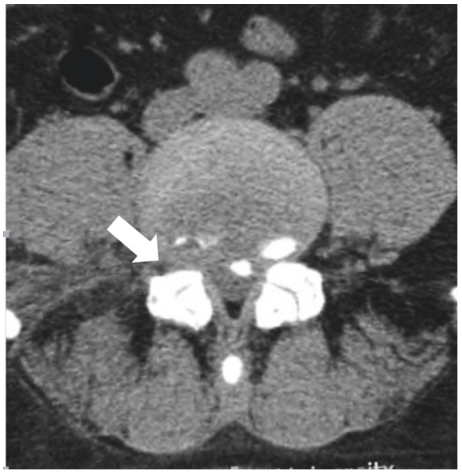


Figure 4: Postop axial CT image (white arrow) shows enlargement of narrowed foramen (compared to contralateral side) and preservement of the facet joint.

## 3. Discussion

Foraminoplasty has been reported as a useful surgical strategy in degenerative lumbar foraminal stenosis, in which the nerve root is entrapped in a narrowed foramen [7, 12, 15, 21, 23, 24]. Traditionally, foraminoplasty could be categorized into two classifications: fluoroscopy-dependent or endoscopy-dependent. Many specialized microsurgical tools for foraminal stenosis decompression have been described, ranging from reamers and trephines to endoscopic drills and lasers [13, 25, 26].

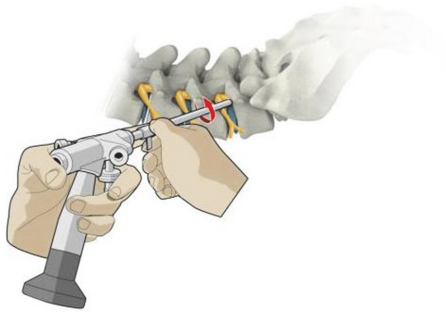


Figure 5: A diagrammatic sketch showing how the endoscopy works as the rotational shaving axis while the surgeon rotates the working cannula. During this procedure, some ligamentous flavum and other foraminal ligaments should be left between the bevel tip and the neurostructure to avoid any nerve damage during the procedure.

Fluoroscopy-dependent tools, such as sequential reamers or trophies, are potent and can rapidly cut off hypertrophied SAP. However, safety is a concern, because sequential reaming can lead to neural injury and accidental bleeding [17–20, 27, 28]. Because of these issues, the procedure must be carefully monitored under fluoroscopy, and the reamer tip should not advance over the medial-pedicle line [21]. This means that both patients and surgeons risk multiple radiation exposures [29, 30]. In contrast, the Kiss-Hug maneuver is conducted under endoscopic guidance, so the amount of fluoroscopic exposure is significantly reduced. Most neural injury incurred during fluoroscopy-dependent foraminoplasty is related to the serrated tip of the bone reamer advancing too far beyond the medial border of the facet joint. As opposed to the bone reamer or the trephine, the distal tip of the working cannula contains no saw structures. The beveled tip is smooth and blunt, and it is not sharp enough to cut through the foraminal ligament. If this maneuver proceeds under general anesthesia, the ligament flavum and the intraforaminal ligament function as an anatomical barrier to prevent neural injury. In the circumstances of local anesthesia, instant feedback from the patient throughout the procedure if he or she is experiencing leg pain might add extra help.

Meanwhile, excellent endoscopic burr systems such as the ultra-thin high-speed drill and the articulated burr [7, 15, 22] could provide safer and more efficient foraminotomy effect than any trephine or bone reamer. The surgeon could accomplish this foraminoplasty under direct endoscopic observation, minimizing neural injury and potential bleeding. However, compared with the fluoroscopy-guided option, expensive additional equipment is needed for these procedures. The Kiss-Hug maneuver utilizes the rotational movement of the working cannula without any other equipment and can remove bony structures more efficiently (Kiss-Hug maneuver takes approximately five to ten seconds) than other methods. Because it is hand-driven, the Kiss-Hug maneuver also avoids the risk of heat-damage to the surrounding spinal nerves that has been reported in other endoscopic procedures [31, 32]. Another issue with endoscopic burr systems is that it is very bulky and difficult to manipulate. Navigating the burr can be challenging; sometimes, the surgeon even needs help from an assistant to hold and manage the equipment. In contrast, the working cannula used for the Kiss-Hug maneuver has a relatively short leverage and can be driven by hand. It provides better force feedback and more precise control than other tools.

One of the advantages of endoscopic foraminoplasty is that it can be individualized for each patient and the specific pathology of the narrowed foramen [33]. Using the elasticity of the surrounding skin and muscle tissue as a fulcrum, the position and direction of the beveled tip can easily be adjusted [13, 33–35]. A surgeon can remove hypertrophied osteophytes from the SAP by hand, particularly the marginal osteophyte that hinders the passage of the working cannula.

Many articles have reported that patients experience a great amount of pain during foraminoplasty, so most surgeons use anesthetics (10–20 ml) on the SAP surface [10, 12, 13, 34–37]. We have not experienced this problem in our practice, perhaps because we routinely coagulate the soft tissue on the SAP's ventral surface before conducting the Kiss-Hug maneuver. During this coagulation step, the sino-vertebral nerve surrounding the foramen may become desensitized.

Another concern in foraminoplasty is the risk of bleeding from an injury to the venous sinus or the bony facet surface. The way we handle this issue in the Kiss-Hug maneuver is not different from other techniques [7, 38, 39]. Most intraoperative bleeding is minimal and spontaneously controlled by compression with the working cannula. Soft tissue bleeding can be managed with a flexible bipolar radiofrequency probe.

Although the Kiss-Hug technique has produced favorable results, some technical limitations remain. Not all kinds of foraminal stenosis can be treated using the Kiss-Hug maneuver, and the indication of Kiss-Hug maneuver is not identical to other endoscopic foraminoplasty tools. For example, a diamond burr is often used for bone removal near important structures, because it is less likely to cause injury, given its delicate drilling capabilities compared to a fluted steel burr [15]. Laser has the potential to remove osteophytes as well as inflamed soft tissue, including hypertrophied capsule, within a narrowed foramen [31]. The best use of the Kiss-Hug maneuver is at the beginning stage of foraminoplasty, so that the surgeon can easily shave off a large amount of bony structure within seconds, enhancing his working efficiency. For deep, localized, and small osteophytes in the stenotic canal, other specialized tools such as the power-articulated burr or the side-firing laser are more appropriate. The Kiss-Hug technique is an alternative surgical option to be considered for foraminoplasty procedure. Meanwhile, the working cannula is not designed to cut any bone tissue; there will be an additional concern for the instrumental failure or breakage in younger patients with stiffer bony structure. When the working cannula hugs the ventral portion of the SAP, the shear stress on the bevel tip might cause it to break. The possibility of tip fracture is higher when undercutting larger pieces of osteophyte. Therefore, we suggest using piecemeal methods. Finally, care should be taken to avoid using the working cannula in a defective or damaged condition, since an articulated drill could accidentally burr the inner surface

of the working cannula and cause weak points during the procedure.

## 4. Conclusions

Our experiences indicate that working cannula-based foraminoplasty could be a viable complement to conventional methods of endoscopic foraminoplasty, and it has some competitive advantages over other surgical tools, including better force feedback, higher cutting efficiency, and more precise control.

## Data Availability

The technical data of foraminoplasty used to support the findings of this study are included in the article.

## Conflicts of Interest

The authors report no conflicts of interest concerning the materials or methods used in this study or the findings described in this paper. No benefits in any form have been or will be received from any commercial party related directly or indirectly to the subject of this manuscript. The authors have full control of all primary data and that they agree to allow the journal to review their data if requested.

## Authors' Contributions

Suxi Gu, Kedong Hou, and Wei Jian contributed equally to this article; they together contributed to statistical analysis, writing, and revision of the manuscript; Jianwei Du contributed to data analysis and revision of the manuscript; Songhua Xiao contributed to planning and revision of the manuscript and data analysis; Xifeng Zhang contributed to planning, statistical analysis, and writing and editing of the manuscript.

## Acknowledgments

This project is supported by Beijing Natural Science Foundation (no. 7184256, Suxi Gu MD), Beijing Municipal Administration of Hospitals' Youth Program (Suxi Gu MD), and Beijing Tsinghua Changgung Hospital Fund (no. 12017C1010, Suxi Gu MD.) Thanks are due to Yilin ZHOU for his art works.

## Supplementary Materials

An endoscopic video of working cannula-based foraminoplasty (Kiss-Hug maneuver). We use the bevel tip of a working cannula as a bone reamer to enlarge the foramen. *(Supplementary Materials)*

## References

[1] E. J. Carragee, A. O. Spinnickie, T. F. Alamin, and S. Paragioudakis, "A prospective controlled study of limited versus subtotal posterior discectomy: short-term outcomes in patients with herniated lumbar intervertebral discs and large posterior anular defect," *The Spine Journal*, vol. 31, no. 6, pp. 653–657, 2006.

[2] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Recurrent lumbar disc herniation after conventional discectomy: a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision," *Journal of Spinal Disorders & Techniques*, vol. 22, no. 2, pp. 122–129, 2009.

[3] K.-C. Choi, J.-S. Kim, and C.-K. Park, "Percutaneous endoscopic lumbar discectomy as an alternative to open lumbar microdiscectomy for large lumbar disc herniation," *Pain Physician*, vol. 19, no. 2, pp. E291–E300, 2016.

[4] S. S. Eun, S. H. Lee, and L. A. Sabal, "Long-term follow-up results of percutaneous endoscopic lumbar discectomy," *Pain Physician*, vol. 19, no. 8, pp. E1161–E1166, 2016.

[5] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique. A prospective, randomized, controlled study," *The Spine Journal*, vol. 33, no. 9, pp. 931–939, 2008.

[6] J. Yokosuka, Y. Oshima, T. Kaneko, Y. Takano, H. Inanam, and H. Koga, "Advantages and disadvantages of posterolateral approach for percutaneous endoscopic lumbar discectomy," *Journal of Spine Surgery*, vol. 2, no. 3, pp. 158–166, 2016.

[7] Y. Ahn, S.-H. Lee, W.-M. Park, and H.-Y. Lee, "Posterolateral percutaneous endoscopic lumbar foraminotomy for L5-S1 foraminal or lateral exit zone stenosis. Technical note," *Journal of Neurosurgery*, vol. 99, no. 3, pp. 320–323, 2003.

[8] S. S. Eun, S. H. Lee, and H. Y. Erken, "Transforaminal percutaneous endoscopic lumbar diskectomy for downmigrated disk herniations: lever-up, rotate, and tilt technique," *Journal of Neurological Surgery Part A: Central European Neurosurgery*, vol. 79, no. 02, pp. 163–168, 2018.

[9] S. G. Osman, K. Nibu, M. M. Panjabi, E. B. Marsolais, and R. Chaudhary, "Transforaminal and posterior decompressions of the lumbar spine: a comparative study of stability and intervertebral foramen area," *The Spine Journal*, vol. 22, no. 15, pp. 1690–1695, 1997.

[10] A. Telfeian, "Endoscopic foraminotomy for recurrent lumbar radiculopathy after TLIF: Technical report," *Surgical Neurology International*, vol. 6, no. 1, 2015.

[11] M. T. N. Knight, I. Jago, C. Norris, L. Midwinter, C. Boynes, and L. Acu, "Transforaminal endoscopic lumbar decompression & foraminoplasty: A 10 year prospective survivability outcome study of the treatment of foraminal stenosis and failed back surgery," *International Journal of Spine Surgery*, vol. 8, 2014.

[12] Y. Ahn, H.-K. Oh, H. Kim, S.-H. Lee, and H.-N. Lee, "Percutaneous endoscopic lumbar foraminotomy: An advanced surgical technique and clinical outcomes," *Neurosurgery*, vol. 75, no. 2, pp. 124–132, 2014.

[13] Y. Ahn, "Percutaneous endoscopic decompression for lumbar spinal stenosis," *Expert Review of Medical Devices*, vol. 11, no. 6, pp. 605–616, 2014.

[14] G. P. Jasper, G. M. Francisco, D. Aghion, and A. E. Telfeian, "Technical considerations in transforaminal endoscopic discectomy with foraminoplasty for the treatment of spondylolisthesis: Case report," *Clinical Neurology and Neurosurgery*, vol. 119, pp. 84–87, 2014.

[15] G. Choi, S.-H. Lee, P. Lokhande et al., "Percutaneous endoscopic approach for highly migrated intracanal disc herniations by

foraminoplastic technique using rigid working channel endoscope," *The Spine Journal*, vol. 33, no. 15, pp. E508–E515, 2008.

[16] S.-S. Ahn, S.-H. Kim, and D.-W. Kim, "Learning curve of percutaneous endoscopic lumbar discectomy based on the period (Early vs. Late) and technique (in-and-out vs. in-and-out-and-in): a retrospective comparative study," *Journal of Korean Neurosurgical Society*, vol. 58, no. 6, pp. 539–546, 2015.

[17] H.-J. Lee, J.-S. Kim, and K.-S. Ryu, "Transforaminal percutaneous endoscopic lumbar diskectomy with percutaneous epidural neuroplasty in lumbar disk herniation: technical note," *World Neurosurgery*, vol. 98, pp. 823–876, 2017.

[18] Y. Ahn, "Transforaminal percutaneous endoscopic lumbar discectomy: Technical tips to prevent complications," *Expert Review of Medical Devices*, vol. 9, no. 4, pp. 361–366, 2012.

[19] J.-S. Kim, G. Choi, and S.-H. Lee, "Percutaneous endoscopic lumbar discectomy via contralateral approach: A technical case report," *The Spine Journal*, vol. 36, no. 17, pp. E1173–E1178, 2011.

[20] Y. Ahn, S.-H. Lee, J. H. Lee, J. U. Kim, and W. C. Liu, "Transforaminal percutaneous endoscopic lumbar discectomy for upper lumbar disc herniation: clinical outcome, prognostic factors, and technical consideration," *Acta Neurochirurgica*, vol. 151, no. 3, pp. 199–206, 2009.

[21] J. S. Kim, H. S. Kang, G. Choi et al., "Foraminoplastic ventral epidural approach for removal of extruded herniated fragment at the L5-S1 level," *Neurologia Medico-Chirurgica*, vol. 50, no. 12, pp. 1074–1078, 2010.

[22] M. T. N. Knight, A. Goswami, J. T. Patko, and N. Buxton, "Endoscopic foraminoplasty: a prospective study on 250 consecutive patients with independent evaluation," *Journal of Clinical Laser Medicine & Surgery*, vol. 19, no. 2, pp. 73–81, 2001.

[23] A. I. Evins, M. A. Banu, I. Njoku et al., "Endoscopic lumbar foraminotomy," *Journal of Clinical Neuroscience*, vol. 22, no. 4, pp. 730–734, 2015.

[24] Ł. Kubaszewski, J. Kaczmarczyk, A. Nowakowski, and A. Sulewski, "Foraminoplastic transfacet epidural endoscopic approach for removal of intraforaminal disc herniation at the L5-S1 level," *Wideochirurgia i Inne Techniki Maloinwazyjne*, vol. 9, no. 1, pp. 96–100, 2014.

[25] K. Kang, J. C. Rodriguez-Olaverri, F. Schwab, J. Hashem, A. Razi, and J. P. Farcy, "Partial facetectomy for lumbar foraminal stenosis," *Advances in Orthopedics*, vol. 2014, Article ID 534658, 4 pages, 2014.

[26] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Use of newly developed instruments and endoscopes: full-endoscopic resection of lumbar disc herniations via the interlaminar and lateral transforaminal approach," *Journal of Neurosurgery: Spine*, vol. 6, no. 6, pp. 521–530, 2007.

[27] G. Fan, T. Wang, S. Hu, X. Guan, X. Gu, and S. He, "Isocentric navigation of percutaneous endoscopic transforaminal discectomy at the L5/S1 level in difficult puncture cases: A technical note," *Pain Physician*, vol. 20, no. 4, pp. E531–E540, 2017.

[28] G. Choi, N. Prada, H. N. Modi, N. B. Vasavada, J.-S. Kim, and S.-H. Lee, "Percutaneous endoscopic lumbar herniectomy for high-grade down-migrated L4–L5 disc through an L5-S1 interlaminar approach: a technical note," *Minimally Invasive Neurosurgery*, vol. 53, no. 3, pp. 147–152, 2010.

[29] Y. Ahn, C.-H. Kim, J. H. Lee, S.-H. Lee, and J.-S. Kim, "Radiation exposure to the surgeon during percutaneous endoscopic lumbar discectomy: A prospective study," *The Spine Journal*, vol. 38, no. 7, pp. 617–625, 2013.

[30] M. Iprenburg, R. Wagner, A. Godschalx, and A. E. Telfeian, "Patient radiation exposure during transforaminal lumbar endoscopic spine surgery: A prospective study," *Neurosurgical Focus*, vol. 40, no. 2, pp. 1–4, 2016.

[31] M. I. Hafez, R. R. Coombs, S. Zhou, and I. D. McCarthy, "Ablation of bone, cartilage, and facet joint capsule using Ho:YAG laser," *Journal of Clinical Laser Medicine & Surgery*, vol. 20, no. 5, pp. 251–255, 2002.

[32] M. I. Hafez, S. Zhou, R. R. H. Coombs, and I. D. McCarthy, "The effect of irrigation on peak temperatures in nerve root, dura, and intervertebral disc during laser-assisted foraminoplasty," *Lasers in Surgery and Medicine*, vol. 29, no. 1, pp. 33–37, 2001.

[33] K.-C. Choi, H.-K. Shim, C. J. Park, and D. C. Lee, "Usefulness of percutaneous endoscopic lumbar foraminoplasty for lumbar disc herniation," *World Neurosurgery*, vol. 106, pp. 484–492, 2017.

[34] Y. Ahn, I. Jang, and W. Kim, "Transforaminal percutaneous endoscopic lumbar discectomy for very high-grade migrated disc herniation," *Clinical Neurology and Neurosurgery*, vol. 147, pp. 11–17, 2016.

[35] G. Choi, S.-H. Lee, K. Deshpande, and H. Choi, "Working channel endoscope in lumbar spine surgery," *Journal of Neurosurgical Sciences*, vol. 58, no. 2, pp. 77–85, 2014.

[36] Z.-Z. Li, S.-X. Hou, W.-L. Shang, Z. Cao, and H.-L. Zhao, "Percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar decompression for lateral recess stenosis through transforaminal approach: technique notes and 2 years follow-up," *Clinical Neurology and Neurosurgery*, vol. 143, pp. 90–94, 2016.

[37] K. Choi, D. C. Lee, and C. Park, "Percutaneous Endoscopic Lumbar Foraminoplasty for Resection of Synovial Cyst," *Journal of Minimally Invasive Spine Surgery and Technique*, vol. 1, no. 1, pp. 36–39, 2016.

[38] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9 mm endoscopes: a prospective, randomized, controlled study," *The Spine Journal*, vol. 33, no. 9, pp. 940–948, 2008.

[39] A. T. Yeung and P. M. Tsou, "Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases," *The Spine Journal*, vol. 27, no. 7, pp. 722–731, 2002.

Hindawi
BioMed Research International
Volume 2018, Article ID 7692794, 9 pages
https://doi.org/10.1155/2018/7692794

*Clinical Study*

# Foraminoplasty at the Tip or Base of the Superior Articular Process for Lateral Recess Stenosis in Percutaneous Endoscopic Lumbar Discectomy: A Multicenter, Retrospective, Controlled Study with 2-Year Follow-Up

**Jun-Song Yang,[1] Lei Chu,[2] Chien-Min Chen,[3,4,5] Xiang-Fu Wang,[6] Pei-Gen Xie,[7] Rui Deng,[2] Ke-Xiao Yu,[2] Lei Shi,[2] Zhen-Xing Zhang,[1] Li-Min Rong,[7] Ding-Jun Hao,[1] and Zhong-Liang Deng[2]**

[1]*Department of Spine Surgery, Honghui Hospital, Xi'an Jiaotong University, No. 76 Nanguo Road, Xi'an, Shaanxi, China*
[2]*Department of Orthopaedics, The Second Affiliated Hospital, Chongqing Medical University, No. 76 Linjiang Road, District Yuzhong, Chongqing, China*
[3]*Department of Neurosurgery, Changhua Christian Hospital, Changhua City, Taiwan*
[4]*School of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*
[5]*College of Nursing and Health Sciences, Dayeh University, China*
[6]*Department of Spinal Minimally Invasive Surgery, Gansu Provincial Hospital of Traditional Chinese Medicine, No. 418 Guazhou Road, District Qilihe, Lanzhou, Gansu, China*
[7]*Department of Spine Surgery, Third Affiliated Hospital, Sun Yat-sen University, Guangzhou, China*

Correspondence should be addressed to Ding-Jun Hao; dingjunhao@qq.com

Jun-Song Yang, Lei Chu, and Rui Deng contributed equally to this work.

Received 13 September 2018; Accepted 6 December 2018; Published 19 December 2018

Guest Editor: Hyeun S. Kim



*Objective*. To compare the clinical efficacy and complications which obtained foraminoplasty at the tip or base of the superior articular process (SAP) for the patients with lateral recess stenosis treated by percutaneous endoscopic lumbar discectomy (PELD). *Methods*. Between January 2015 and January 2016, 156 patients of lumbar disc herniation accompanying with lateral recess stenosis were treated with PELD in five tertiary hospitals and fulfilled the 2-year follow-up. Among them, 78 patients obtained a foraminoplasty at the tip of SAP (group A), and foraminoplasty at the base of SAP was performed in the other 78 cases (group B). Clinical efficacy was evaluated using the visual analog scale (VAS) score for back and leg pain, Oswestry Disability Index (ODI), and 36-item Short-Form Health Survey (SF-36) score. The intervals of follow-up were scheduled at 1 month, 3 months, 6 months, 1 year, and 2 years after surgery. *Results*. Mean operative duration is shorter in group B (55 versus 61 min, $P = 0.047$). Only one case belonged to group A could not tolerate the neural irritation and required conversion to an open procedure. During the surgery, no dura tears, cauda equina syndrome, or infections were observed. 5 patients experienced transient dysesthesia located at the exiting nerve in group A, while no cases complained dysesthesia in group B. 2 cases who suffered temporary motor weakness all belonged to group A. A total of 5 cases obtained a revision surgery after recurrence in the follow-up, in which 3 patients belonged to group A. Compared to the preoperative data, significant improvements in VAS scores of low back pain and sciatica, ODI, and SF-36 PCS and MC were observed in the follow-up, respectively ($P < 0.05$, respectively). However, no statistical difference was observed at all time-points after surgery between these two groups ($P > 0.05$, respectively). *Conclusions*. For the patients of LDH accompanying with lateral recess stenosis, compared with the routine foraminoplasty at the tip of SAP, our modified foraminoplastic technique does not only change place of foraminoplasty to the base of SAP but also simplified puncture process in transforaminal PELD. Although there was no significant difference in symptom relief, the modified foraminoplasty showed the advantages in decreasing the incidence of postoperative neural dysfunction and reducing operation time.

Table 1: Summary of demographic and treatment level.

| Baseline characteristic | Group A | Group B |
|---|---|---|
| Female gender (%) | 43 (44.9) | 49 (37.2) |
| Mean age (yrs) (range) | 54.3 (45-65) | 53.5 (52-68) |
| Treatment level | | |
| L3-4 (%) | 12 (15.4) | 15 (19.2) |
| L4-5 (%) | 43 (55.1) | 41 (52.6) |
| L5-S1 (%) | 23 (29.5) | 22 (28.2) |

SAP: superior articular process.

## 1. Introduction

Since the introduction of the percutaneous discectomy by Kambin in 1973 [1], transforaminal percutaneous endoscopic lumbar discectomy (PELD) has recently been an increasingly popular surgical procedure to treat lumbar disc herniation, which bridges the gap between conservative treatment and traditional surgery. Numerous studies have proved that PELD provide successful outcomes comparable to conventional open or microendoscopic surgery [2–7]. However, it showed the advantages in controlling muscular trauma, shortening hospital stay, and maintaining the spinal segment stability [2, 7, 8]. As the neural decompression was performed under a single port, how to precisely establish an ideal working cannula toward the targeted lesion is the base of PELD. Superior articular process (SAP) is the main culprit between the posterolateral rod-shaped endoscope and the anteromedial dura sac, especially for the elderly patients with hypertrophic facet joint and lateral recess stenosis. To address the problem, some authors have raised the technique of endoscopic foraminoplasty by using a reamer, drill, or laser, which widens the lumbar intervertebral foramen and facilitates the establishment of working sheath [9–15]. However, foraminoplasty-related complications, like postoperative dysesthesia and motor weakness associated with the nerve root injury, are the principal concerns of performing foraminoplasty in PELD [9, 15]. The classical foraminoplasty, the so-called Tessys technique described by Schubert and Hoogland, was toward to the tip of SAP [16, 17]. As the SAP, the posterior border of intervertebral lumbar foramen, without the protection from the outside sheath, the trephine makes direct contact with paraforamen soft tissue, causing concerns about damage to the exiting nerve root and dura sac; thus extent of foraminoplasty, the extent of SAP removing, was limited [18]. Anatomatically, because the base of SAP was far away from the exiting nerve root, a foraminoplasty which targeted the base of SAP could provide thorough foraminoplasty decreasing the iatrogenic injury of nerve root. To compare the clinical efficacy and complications which obtained foraminoplasty at the tip or base of the SAP, we first perform a multicenter study for the patients with lateral recess stenosis treated by PELD.

## 2. Method

Between January 2015 and January 2016, 156 patients of lumbar disc herniation accompanying with lateral recess stenosis were treated with PELD in five tertiary hospitals and fulfilled the 2-year follow-up. Among them, the first 78 patients obtained a foraminoplasty at the tip of SAP (group A), and foraminoplasty at the base of SAP was performed in the secondary 78 cases (group B). Patient demographics and characteristics are summarized in Table 1. Approval to conduct the study was granted by the ethics committees of hospitals. Institutional Review Board approved informed consent and protocols were also provided to all patients.

Inclusion criteria are as follows: (1) clinical signs of neurological deficit including radiculopathy, paresthesia, and motor weakness; (2) symptoms corresponding with preoperative magnetic resonance imaging (MRI) of computed tomography (CT) scan and concordant with lateral recess stenosis (the anteroposterior diameter of the lateral recess was less than 4 mm); (3) unsatisfactory conservative treatment for at least 6 weeks; (4) patients who wrote informed consent to participate in this evaluation and further follow-ups.

Exclusion criteria are as follows: (1) definite segmental instability (the anterior or posterior displacement > 3 mm or the angle change of the endplate > 15 degrees on the dynamic radiography); (2) cauda equina syndrome with severe central canal stenosis (less than 10 mm) on preoperative MRI or CT; (3) highly migrated nucleus pulposus beyond the low rims of adjacent pedicles; (4) high iliac crest without enough space for addressing the disc herniation at the L5-S1 level via a posteriolateral transforaminal approach; (5) suspected infection or Malignant diseases.

## 3. Surgical Technique

All patients obtained PELD via a transforaminal approach under local anesthesia in the prone position. Dexmedetomidine hydrochloride (0.5 $\mu$g/kg bolus, followed by 0.1–0.5 $\mu$g/kg/hour) was injected intravenously could improve the patient's surgical tolerance. Entry point of needle was determined by the point of intersection between the horizontal line and the oblique caudal directional line tangent with the tip of SAP. A 16G spinal needle was utilized in the puncture process, whose diameter was larger than the routine 20G spinal needle and better to adjust the puncture trajectory in the strong back muscles. For avoiding the iatrogenic injury to the peritoneal sac, the puncture trajectory was slightly dorsal toward rather the intervertebral foramen. The spinal needle was first placed on the dorsal surface of facet joint (Figure 1). Under the guidance of spinal

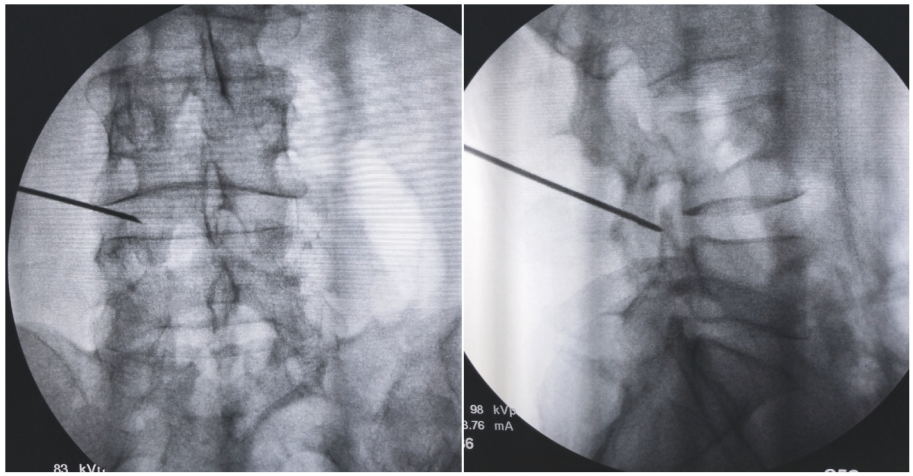


Figure 1: The puncture needle was first placed on the dorsal surface of facet joint, which was confirmed by the anteroposterior (left) and lateral (right) views of fluoroscopy.

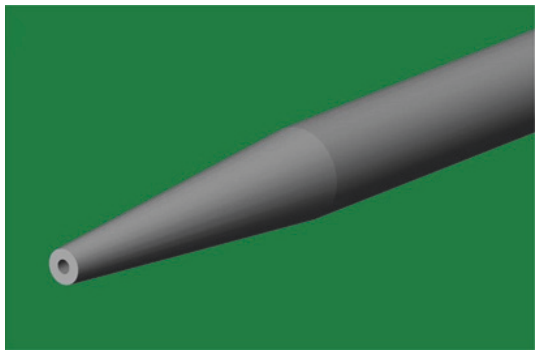
needle, a topical anesthesia was performed in the capsule of facet joint. Another spinal needle was introduced to perform infiltrating anesthesia into the paraspinal muscles with 8–10 ml of 0.5% lidocaine from the skin at the insertion site and along the needle entry tract. Then, the stylet of spinal needle was replaced by a guide wire, and the outside sheath was removed. A stab incision of approximately 5 mm long was made around the guide wire. Along with the guide wire, a blunt guide rod with a pencil head-shaped end was introduced and placed at the surface of SAP (Figure 2), and the inner guide wire was retrieved. Under the guidance of lateral bony margin of SAP, the tapered end of the cannulated guide rod was slid into the intervertebral foramen and fixed by the around bony fracture and soft tissue. According to the foraminoplasty toward to the tip or base of the SAP, the guide rod was placed at the upper or lower part of intervertebral foramen. The protective cannula could be introduced toward the SAP along the guide rod. A topical anesthesia could be added according the tolerance of patients thorough the protective cannula. As the distal end of protective cannula was e bevel half shaped, which could cover the tip or base of the ventral part of SAP (Figure 3). A trephine was inserted into the protective cannula to perform foraminoplasty via the transforaminal approach. As the tip of protective cannula anchored in foramen is like a fulcrum, the lateral side of trephine together with the protective cannula was downward nearly horizontally to remove the ventral hypertrophic SAP as much as possible, even the inferior articular process of cranial vertebra, and expand the narrow lateral recess (Figure 4). It was notable that the process of trephine advancing should be close monitored under fluoroscopy. Protective cannula was replaced with working cannula. An endoscope (SPINENDOS GmbH, Munich, Germany) with a working channel of 4.3-mm outside diameter is introduced. Because the narrow lateral recess and intervertebral foramen were adequately enlarged, additional maneuvers like levering the cannula to make it more horizontal could be easily achieved without the irritation to the ventral exiting nerve root. After removing the hypertrophic ligamentum flavum, the nerve root and the protruded nucleus pulposus were gradually recognized under endoscopic visualization. When the protruded nucleus pulposus was thoroughly removed, the crevasse of annulus fibrosus was detected. Annuloplasty was performed to prevent the recurrent herniation of intradiscal nucleus pulposus. The surgery was halted when the satisfactory decompression of traversing nerve root and dura sac was confirmed.

## 4. Postoperative Management and Outcome Assessment

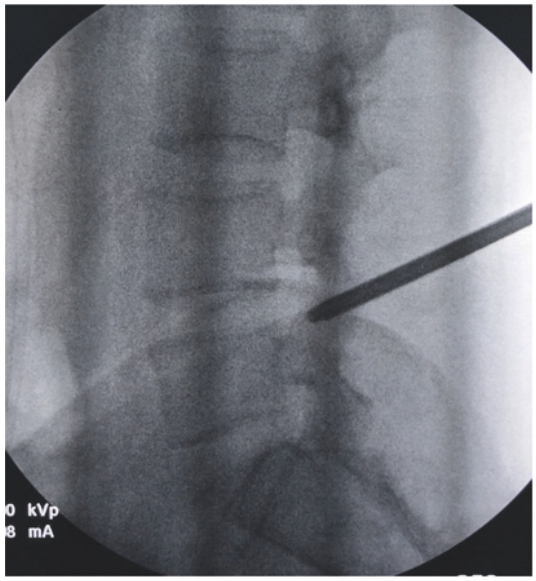
To decrease the possibility of recurrence of postoperative disc herniation, the lumbar brace was recommend to wear for approximately 4 weeks to ensure that the ruptured annular fibrosis could achieve satisfactory healing. The intensity of back and leg pain was assessed by visual analog scale (VAS) score retrospectively. Functional outcomes were assessed by using Oswestry Disability Index (ODI) score and SF-36. The intervals of follow-up were scheduled at 1 month, 3 months, 6 months, 1 year, and 2 years after surgery. The physical examinations and clinical scores were performed by another surgeon who did not participate in surgery procedures. The related complications, including postoperative dysesthesia and motor weakness, were also recorded. Postoperative MRI and CT examinations were obtained in all patients routinely at postoperative 1 day to detect whether residual disc was occurred (Figures 5 and 6). Dynamic lumbar radiography was recommended at the final follow-up.

## 5. Statistical Analysis

Statistical analyses were performed with SPSS 11.5 software (SPSS Inc., Chicago, IL). Preoperative and postoperative VAS scores of back and leg pain as well as ODI and SF-36 values were analyzed with ANOVA retrospectively. $P < 0.05$ was considered as significant.



(a)




(b)

Figure 2: The guide rod is blunt with a pencil head-shaped end (Panel (a)); it was placed on the dorsal surface of facet joint, which was confirmed by the lateral (Panel (b)) view of fluoroscopy.

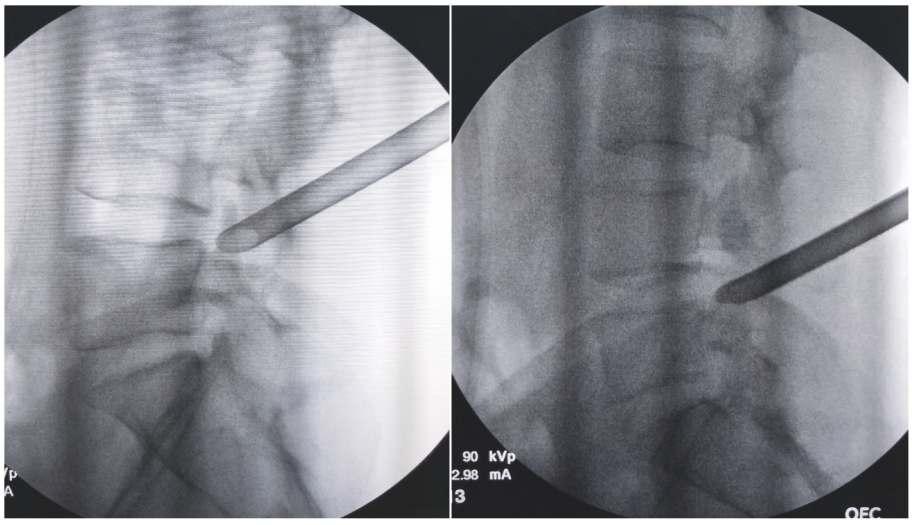



Figure 3: The base (left) or tip (right) of the ventral part of SAP was covered by the protective cannula at the lateral views of fluoroscopy.

Table 2: Changes of preoperative and postoperative VAS scores of low back pain ($x \pm s$).

| Time point | Pre-operation | 1 months postoperatively | 3 months postoperatively | 6 months postoperatively | 1 year postoperatively | 2 years postoperatively |
|---|---|---|---|---|---|---|
| Group A | 5.1±0.7 | 3.2±0.6 | 2.5±0.8 | 2.1±0.4 | 1.6±0.3 | 1.5±0.4 |
| Group B | 5.0±0.9 | 3.0±0.7 | 2.8±0.6 | 2.0±0.3 | 1.7±0.5 | 1.4±0.5 |

*VAS: visual analogue scale.*

Table 3: Changes of preoperative and postoperative VAS scores of sciatica ($x \pm s$).

| Time point | Pre-operation | 1 months postoperatively | 3 months postoperatively | 6 months postoperatively | 1 year postoperatively | 2 years postoperatively |
|---|---|---|---|---|---|---|
| Group A | 7.1±0.8 | 2.2±0.8 | 2.0±0.5 | 1.8±0.5 | 1.6±0.3 | 1.5±0.3 |
| Group B | 7.0±0.9 | 2.0±0.7 | 1.9±0.4 | 1.7±0.4 | 1.5±0.4 | 1.4±0.2 |

*VAS: visual analogue scale.*

Table 4: Changes of preoperative and postoperative ODI scores ($x \pm s$).

| Time point | Pre-operation | 1 months postoperatively | 3 months postoperatively | 6 months postoperatively | 1 year postoperatively | 2 years postoperatively |
|---|---|---|---|---|---|---|
| Group A | 50.1±6.9 | 34.5±5.6 | 20.4±5.3 | 18.1±4.3 | 16.8±3.8 | 14.6±3.2 |
| Group B | 50.4±5.3 | 33.8±5.4 | 20.9±4.4 | 17.8±4.5 | 16.9±3.1 | 14.7±3.0 |

*ODI: Oswestry Disability Index.*

Table 5: Changes of preoperative and postoperative SF-36 MC scores ($x \pm s$).

| Time point | Pre-operation | 1 year postoperatively | 2 years postoperatively |
|---|---|---|---|
| Group A | 28.4±8.1 | 50.8±9.3 | 65.2±8.1 |
| Group B | 29.1±7.7 | 51.3±10.1 | 64.1±7.3 |

*MC:* ***mental component.***

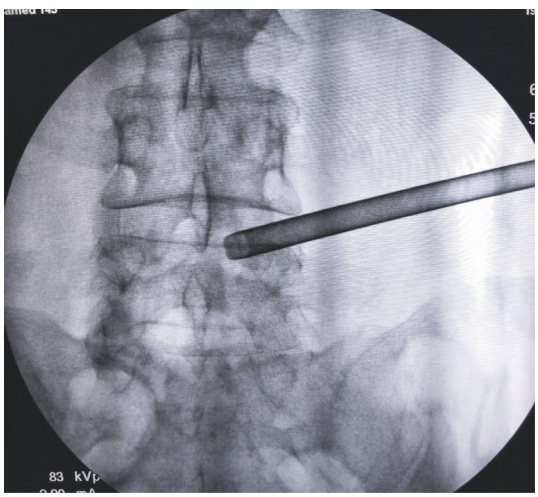



Figure 4: Because the ventral hypertrophic SAP was removed as much as possible, the protective cannula can be placed beyond the medial margin of inferior articular process, which was confirmed by the anteroposterior view of fluoroscopy.

## 6. Results

Mean operative duration is shorter in group B (55 versus 61 min, P = 0.047). Only one case in the group A could not tolerate the neural irritation and required conversion to an open procedure. During the surgery, no dura tears, cauda equina syndrome, or infections were observed in the present case series. 5 patients experienced transient dysesthesia located at the exiting nerve in the group A, while no cases complained dysesthesia in group B. 2 cases suffered temporary motor weakness all belonged to group A. A total of 5 cases obtained a revision surgery after recurrence in the follow-up, in which 3 patients belonged to group A. Preoperative and postoperative VAS scores of low back pain and sciatica, ODI, and SF-36 PCS and MC are summarized in Tables 2–6, respectively. Compared to the preoperative data, a significant improvement in VAS scores of low back pain and sciatica, ODI, and SF-36 PCS and MC were observed in the follow-up, respectively ($P < 0.05$, respectively). However, no statistical difference was observed at all time-points after surgery between these two groups ($P > 0.05$, respectively).

## 7. Discussion

As the most widely used endoscopic approach in the treatment of LDH, transforaminal PELD to optimize the route to the spinal canal percutaneously has been described since the late 1990s and obtained satisfactory clinical outcome [19]. However, among the perioperative complications, incomplete or unsuccessful removal of disc fragments is relatively

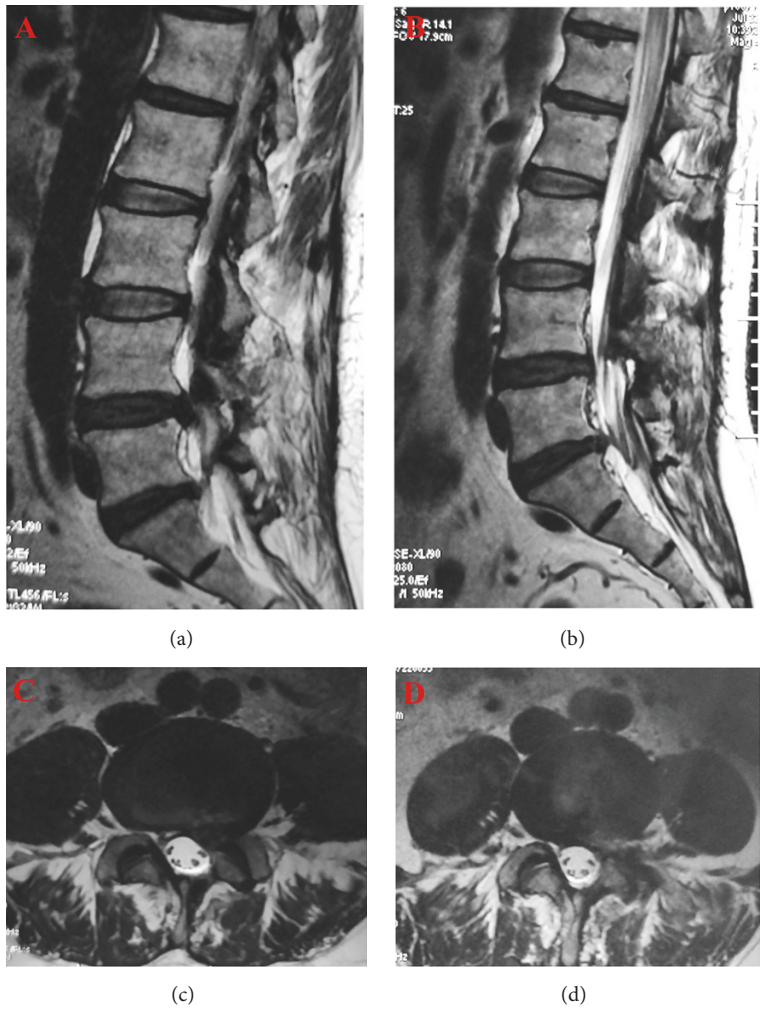



Figure 5: In the preoperative MRI, the sagittal (Panel (a)) and axial (Panel (b)) planes of T2-weighted imaging showed a lumbar disc herniation at the level L4/5. The decompression was satisfactory, which was confirmed at the sagittal (Panel (c)) and axial (Panel (d)) planes of the postoperative MRI.

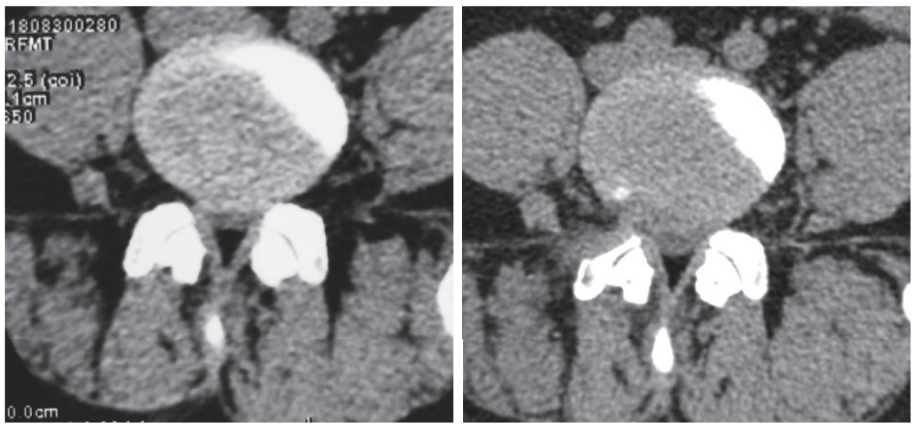



Figure 6: Compared to the preoperative CT scan (Panel A), the herniated disc to the right side was totally remove at the postoperative CT scan (Panel B). Notably, the hypertrophic SAP at the right side was partially removed.

Table 6: Changes of preoperative and postoperative SF-36 MC scores ($x \pm s$).

| Time point | Pre-operation | 1 year postoperatively | 2 years postoperatively |
|---|---|---|---|
| Group A | 28.4±8.1 | 55.8±9.3 | 62.2±8.1 |
| Group B | 29.1±7.7 | 56.3±10.1 | 61.1±7.3 |

*MC:* ***mental component.***

often and clinically worrisome. Unsatisfactory establishment of working channel and residual disc are the main reason of failure of PELD. For complex lumbar disc herniation (LDH), such as central, migrated, and axillary type, and the failure rate of PELD without foraminoplasty is as high as 4.3%-10.3% [20, 21]. As the intervertebral foramen at the lower lumbar region is gradually decreased, the SAP could block the surgical field to the anterior epidural space and limit the manipulated space to place the working channel through the intervertebral foramen access the lesions. In the LDH patients accompanying with lateral recess stenosis, how to widen the intervertebral foramen and lateral recess is quite vital in the process of PELD. Foraminoplasty could provide direct visualization of the anterior epidural space via thorough decompression at the ventral and dorsal structure, especially widening of the foramen by undercutting of ventral part of the SAP and removing the foraminal ligament [22].

The described instrumentations utilized for foraminoplasty include endoscopic burr, side-firing laser, reamers and trephine, etc [9, 15, 16, 21–25]. Endoscopic burr and side-firing laser could remove the SAP under endoscopic visualization improving surgical safety. However, these tools are so tiny to affect the efficiency of foraminoplasty, in which lateral recess was not enough to enlarge because of the restriction of the working channel of the rigid endoscope. Additionally, the process of undercutting of SAP while using a high-speed endoscopic burr or side-firing laser may potentially could lead to vibration stimulation or thermal damage, inducing iatrogenic injury to exit nerve root [24, 25]. Knight et al. observed that temporary nerve irritation noted in 19% of patients postoperatively when a side-firing laser was used for performing foraminoplasty under PELD [9], while Ahn et al. reported the rate of postoperative dysesthesia is 6.1% after endoscopic foraminoplasty with an endoscopic high-speed drill [15]. Compared with endoscopic burr and side-firing laser, a trephine or bone reamer is an economical and time-saving equipment to undercut the hypertrophic SAP or osteophyte under fluoroscopic guidance. However, without the monitor under continuous visualization endoscopic and protection of outside sheath, foraminoplasty with trephine or reamer carries the risk of injury to the exiting and traversing nerve root, which may produce leg pain and neurological dysfunction in the affected extremity. Li et al. modified the current technique of foraminoplasty, in which they change the place of foraminoplasty from the tip of SAP to the base of SAP [26, 27]. As the place of foraminoplasty is far away from the exiting nerve root, the incidence of postoperative nerve root dysfunction is theoretically low. Additionally, a protective cannula was introduced into the process of foraminoplasty to act as a barrier between exiting nerve root and the removing bony structure of SAP. The design of duck-mouth-like distal end can facilitate the protective cannula covering the cambered SAP. When levering the cannula to make it more horizontal, downward or upward tilting, the foraminoplasty could accomplish in individual trajectory under the protection of outer cannula. Besides the tip of SAP, the horizontal part of the SAP and lateral recess medial to the pedicle are the key points of foraminoplasty. However, a foraminoplasty with larger area could not only affect the exit nerve root, but also put the transversing nerve root at risk. As the medial part of SAP is covered by the capsule of facet joint and the ligamentum flavum, they are a buffer to prevent the undercutted portion of the SAP migrated into the spinal canal compressing the transversing nerve root and dura sac. As the bone of the horizontal part of the SAP and lateral recess medial to the pedicle is quite thick and hard [28], an uncontrolled reaming with a greater depth could beyond the limitation of covering ligament structure of SAP. Thus, the trephine could penetrate the medial wall of SAP and violate the transversing nerve root and dura sac. To controlled depth of foraminoplasty, we designed a spacer, which can be fixed at the caudal side of trephine to limit the depth, because the foraminoplasty is not directly toward the exit nerve root but focuses on the surround bony structure. With the process of foraminoplasty, the intervertebral foramen and the lateral recess are gradually enlarged. The created area is a buffer space between the working sheath and the exiting nerve root to facilitate inserting the working cannula more deep toward the targeted lesion decreasing the risk of the iatrogenic injury to the exiting nerve root. That could explain why the incidence postoperative neural dysfunction is low in the group A.

We have improved the puncture procedure and simplified the process. There is no need to place the puncture needle exactly to the tip or the base of SAP but only need to place the puncture needle at the lateral side of SAP. Once the puncture needle is attached to the surface of the facet joint, a blunted guide rod with larger diameter than the puncture needle was introduced along with the guide wire. The guide rod could slide along with the lateral and ventral surface of articular joint and into the intervertebral foramen. Thus, the puncture procedure is simplified; the radiation of intraoperative fluoroscopy and the operation time is controlled. The unique design that the guide rod is blunted with a pencil head-shaped end could facilitate the guide rod sliding and anchoring into the intervertebral foramen. Because the trajectory was slightly toward the dorsal side rather the ventral side and the blunted guide rod replaced with the sharp puncture needle, the risk of perforation of abdominal visceral organs in the puncture process is low.

Excessive removal of the facet joints has been proved to be associated with spinal instability after open surgery [29, 30]. As excessive bone was also removed in the foraminoplasty, whether it could influence the stability of the lumbar segment is not widely explored. Osman et al. made the first cadaveric study to explore the pathological anatomy, intervertebral foraminal area, and flexibility changes between posterior and transforaminal decompression [31]. 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. Li et al. [26, 27] consider that when the anteromedial third of the superior facet, the anterior part of inferior facet, and the portion of the joint between them were removed, there was no violation of the anatomic integrity of the lumbar spine in the procedure of foraminoplasty; the risk of surgically induced instability was minimized after PELD. However, the postoperative stability was not radiologically evaluated. In this controlled study, there is no postoperative instability observed in the surgical spinal unit in the 2-year follow-up. We believe that, besides preserving the anatomic integrity of the lumbar spine, a nearly complete reservation of ligamental and muscular structure is beneficial for maintaining the spinal stability.

Different from the previous studies [26, 27], we used a local anesthetic agent accompanied with dexmedetomidine. Dexmedetomidine hydrochloride is a potent and highly selective alpha-2 agonist, which has been safely used for various diagnostic and therapeutic procedures to facilitate patient comfort [32]. In chronic subdural hematoma evacuation, Surve et al. have proven that dexmedetomidine sedation with local anesthesia was a safe and effective technique for patients undergoing a burr hole procedure [33]. In our previous study, we have successfully removed the epidural leaked cement under local anesthesia accompanied with dexmedetomidine sedation [34].

## 8. Conclusion

For the patients of LDH accompanying with lateral recess stenosis, compared with the routine foraminoplasty at the tip of SAP, our modified foraminoplastic technique is not only changed place of foraminoplasty to the base of SAP but also simplified puncture process in transforaminal PELD. Although there was no significant difference in symptom relief, the modified foraminoplasty showed the advantages in decreasing the incidence of postoperative neural dysfunction and reducing operation time.

## Data Availability

The research related data used to support the findings of this study are restricted by the Ethics Committee of Honghui Hospital, Xi'an Jiaotong University, in order to protect patient privacy. Data are available from Zhong-Liang Deng, email address: 215069125@qq.com, for researchers who meet the criteria for access to confidential data

## Conflicts of Interest

The authors declare that there are no conflicts of interest.

## Authors' Contributions

Lei Chu, Xiang-Fu Wang, Li-Min Rong, and Zhong-Liang Deng conceived the study design. Ke-Xiao Yu, Lei Shi, Zhen-Xing Zhang, Chien-Min Chen, and Rui Deng supervised the data collection. Jun-Song Yang drafted the manuscript. Ding-Jun Hao and Zhong-Liang Deng contributed to the revision. Ding-Jun Hao is responsible for this article. Lei Chu, Jun-Song Yang, Chien-Min Chen, Xiang-Fu Wang, and Pei-Gen Xie contributed equally to this study.

## Acknowledgments

We thank the Key Project of Medical Research of Chongqing Municipal Healthy Bureau (no. 2016ZDXM007 for Zhong-Liang Deng) and Chinese National Natural Science Foundation (no. 81772357 for Ding-Jun Hao) for providing the grant.

## References

[1] P. Kambin and S. Sampson, "Posterolateral percutaneous suction-excision of herniated lumbar intervertebral discs. Report of interim results," *Clinical Orthopaedics and Related Research*, vol. 207, pp. 37–43, 1986.

[2] Y. Ahn, S.-H. Lee, J. H. Lee, J. U. Kim, and W. C. Liu, "Transforaminal percutaneous endoscopic lumbar discectomy for upper lumbar disc herniation: clinical outcome, prognostic factors, and technical consideration," *Acta Neurochirurgica*, vol. 151, no. 3, pp. 199–206, 2009.

[3] F. U. Hermantin, T. Peters, L. Quartararo, and P. Kambin, "A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy," *The Journal of Bone & Joint Surgery—American Volume*, vol. 81, no. 7, pp. 958–965, 1999.

[4] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Full-endoscopic anterior decompression versus conventional anterior decompression and fusion in cervical disc herniations," *International Orthopaedics*, vol. 33, no. 6, pp. 1677–1682, 2009.

[5] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique : a prospective, randomized, controlled study," *Journal of Neurosurgery: Spine*, vol. 10, no. 5, pp. 476–485, 2009.

[6] D. Y. Lee, C. S. Shim, Y. Ahn, Y.-G. Choi, H. J. Kim, and S.-H. Lee, "Comparison of percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for recurrent disc herniation," *Journal of Korean Neurosurgical Society*, vol. 46, no. 6, pp. 515–521, 2009.

[7] C. Birkenmaier, M. Komp, H. F. Leu, B. Wegener, and S. Ruetten, "The current state of endoscopic disc surgery: review of controlled studies comparing full-endoscopic procedures for disc herniations to standard procedures," *Pain Physician*, vol. 16, no. 4, pp. 335–344, 2013.

[8] C.-W. Lee, K.-J. Yoon, S.-S. Ha, and J.-K. Kang, "Foraminoplastic superior vertebral notch approach with reamers in percutaneous endoscopic lumbar discectomy: technical note and clinical outcome in limited indications of percutaneous endoscopic lumbar discectomy," *Journal of Korean Neurosurgical Society*, vol. 59, no. 2, pp. 172–181, 2016.

[9] M. T. N. Knight, I. Jago, C. Norris, L. Midwinter, C. Boynes, and L. Acu, "Transforaminal endoscopic lumbar decompression &

foraminoplasty: A 10 year prospective survivability outcome study of the treatment of foraminal stenosis and failed back surgery," *International Journal of Spine Surgery*, vol. 8, 2014.

[10] Y. Ahn, "Percutaneous endoscopic decompression for lumbar spinal stenosis," *Expert Review of Medical Devices*, vol. 11, no. 6, pp. 605–616, 2014.

[11] Y. Ahn, S.-H. Lee, W.-M. Park, and H.-Y. Lee, "Posterolateral percutaneous endoscopic lumbar foraminotomy for L5-S1 foraminal or lateral exit zone stenosis. Technical note," *Journal of Neurosurgery*, vol. 99, no. 3, pp. 320–323, 2003.

[12] G. P. Jasper, G. M. Francisco, D. Aghion, and A. E. Telfeian, "Technical considerations in transforaminal endoscopic discectomy with foraminoplasty for the treatment of spondylolisthesis: Case report," *Clinical Neurology and Neurosurgery*, vol. 119, pp. 84–87, 2014.

[13] G. P. Jasper, G. M. Francisco, and A. E. Telfeian, "Clinical success of transforaminal endoscopic discectomy with foraminotomy: a retrospective evaluation," *Clinical Neurology and Neurosurgery*, vol. 115, no. 10, pp. 1961–1965, 2013.

[14] M. T. N. Knight, A. Vajda, G. V. Jakab, and S. Awan, "Endoscopic laser foraminoplasty on the lumbar spine—early experience," *Minimally Invasive Neurosurgery*, vol. 41, no. 1, pp. 5–9, 1998.

[15] Y. Ahn, H.-K. Oh, H. Kim, S.-H. Lee, and H.-N. Lee, "Percutaneous endoscopic lumbar foraminotomy: An advanced surgical technique and clinical outcomes," *Neurosurgery*, vol. 75, no. 2, pp. 124–132, 2014.

[16] M. Schubert and T. Hoogland, "Endoscopic transforaminal nucleotomy with foraminoplasty for lumbar disk herniation," *Operative Orthopädie und Traumatologie*, vol. 17, no. 6, pp. 641–661, 2005.

[17] T. Hoogland, M. Schubert, B. Miklitz, and A. Ramirez, "Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases," *The Spine Journal*, vol. 31, no. 24, pp. E890–E897, 2006.

[18] T. Hoogland, K. V. D. Brekel-Dijkstra, M. Schubert, and B. Miklitz, "Endoscopic transforaminal discectomy for recurrent lumbar disc herniation: a prospective, cohort evaluation of 262 consecutive cases," *The Spine Journal*, vol. 33, no. 9, pp. 973–978, 2008.

[19] S. Ruetten, M. Komp, and G. Godolias, "An extreme lateral access for the surgery of lumbar disc herniations inside the spinal canal using the full-endoscopic uniportal transforaminal approach-technique and prospective results of 463 patients," *The Spine Journal*, vol. 30, no. 22, pp. 2570–2578, 2005.

[20] K.-C. Choi, J.-H. Lee, J.-S. Kim et al., "Unsuccessful percutaneous endoscopic lumbar discectomy: a single-center experience of 10,228 cases," *Neurosurgery*, vol. 76, no. 4, pp. 372–380, 2015.

[21] H. Wang, Y. Zhou, C. Li, J. Liu, and L. Xiang, "Risk factors for failure of single-level percutaneous endoscopic lumbar discectomy," *Journal of Neurosurgery: Spine*, vol. 23, no. 3, pp. 320–325, 2015.

[22] G. Choi, S.-H. Lee, P. Lokhande et al., "Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope," *The Spine Journal*, vol. 33, no. 15, pp. E508–E515, 2008.

[23] K.-U. Lewandrowski, ""Outside-in" technique, clinical results, and indications with transforaminal lumbar endoscopic surgery: A retrospective study on 220 patients on applied radiographic classification of foraminal spinal stenosis," *International Journal of Spine Surgery*, vol. 8, 2014.

[24] M. I. Hafez, R. R. H. Coombs, S. Zhou, and I. D. McCarthy, "Ablation of bone, cartilage, and facet joint capsule using Ho:YAG laser," *Journal of Clinical Laser Medicine & Surgery*, vol. 20, no. 5, pp. 251–255, 2002.

[25] M. I. Hafez, S. Zhou, R. R. H. Coombs, and I. D. McCarthy, "The effect of irrigation on peak temperatures in nerve root, dura, and intervertebral disc during laser-assisted foraminoplasty," *Lasers in Surgery and Medicine*, vol. 29, no. 1, pp. 33–37, 2001.

[26] Z.-Z. Li, S.-X. Hou, W.-L. Shang, K.-R. Song, and H.-L. Zhao, "Modified percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar discectomy: Instrument design, technique notes, and 5 years follow-up," *Pain Physician*, vol. 20, no. 1, pp. E85–E98, 2017.

[27] Z.-Z. Li, S.-X. Hou, W.-L. Shang, Z. Cao, and H.-L. Zhao, "Percutaneous lumbar foraminoplasty and percutaneous endoscopic lumbar decompression for lateral recess stenosis through transforaminal approach: technique notes and 2 years follow-up," *Clinical Neurology and Neurosurgery*, vol. 143, pp. 90–94, 2016.

[28] Y. Ahn, S.-H. Lee, W.-M. Park, H.-Y. Lee, S.-W. Shin, and H.-Y. Kang, "Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases," *The Spine Journal*, vol. 29, no. 16, pp. E326–332, 2004.

[29] S. Guo, J. Sun, and G. Tang, "Clinical study of bilateral decompression via vertebral lamina fenestration for lumbar interbody fusion in the treatment of lower lumbar instability," *Experimental and Therapeutic Medicine*, vol. 5, no. 3, pp. 922–926, 2013.

[30] K.-E. Johnsson, S. Willner, and K. Johnsson, "Postoperative instability after decompression for lumbar spinal stenosis," *The Spine Journal*, vol. 11, no. 2, pp. 107–110, 1986.

[31] S. G. Osman, K. Nibu, M. M. Panjabi, E. B. Marsolais, and R. Chaudhary, "Transforaminal and posterior decompressions of the lumbar spine: a comparative study of stability and intervertebral foramen area," *The Spine Journal*, vol. 22, no. 15, pp. 1690–1695, 1997.

[32] K. A. Freeman, D. A. Fullerton, L. S. Foley et al., "Spinal cord protection via alpha-2 agonist-mediated increase in glial cell-line–derived neurotrophic factor," *The Journal of Thoracic and Cardiovascular Surgery*, vol. 149, no. 2, pp. 578–586, 2015.

[33] R. M. Surve, S. Bansal, M. Reddy, and M. Philip, "Dexmedetomidine sedation with local anesthesia is a safe and effective technique for burr hole and evacuation of CSDH," *Journal of Neurosurgical Anesthesiology*, vol. 29, no. 3, pp. 274–280, 2017.

[34] L. Chu, J. Yang, K. Yu, C. Chen, D. Hao, and Z. Deng, "Percutaneous Endoscopic Retrieval of Intraspinal Cement Leakage: Technical Note," *World Neurosurgery*, vol. 118, pp. 150–155, 2018.

Hindawi
BioMed Research International
Volume 2018, Article ID 5806037, 8 pages
https://doi.org/10.1155/2018/5806037

*Research Article*

# Percutaneous Endoscopic Lumbar Interbody Fusion: Technical Note and Preliminary Clinical Experience with 2-Year Follow-Up

**Junlong Wu,[1,2] Huan Liu,[1] Shengxiang Ao,[1] Wenjie Zheng,[1] Changqing Li,[1] Haiyin Li,[1] Yong Pan,[1] Chao Zhang ,[1] and Yue Zhou [1]**

[1]*Department of Orthopaedics, The Second Affiliated Xinqiao Hospital of Army Medical University, Chongqing 400037, China*
[2]*Department of Orthopaedics, Fourth Military of Chinese People Liberation Army, Xining, Qinghai 810007, China*

Correspondence should be addressed to Chao Zhang; tmmuzc@163.com and Yue Zhou; happyzhou@vip.163.com

Received 13 August 2018; Accepted 7 November 2018; Published 19 November 2018

Academic Editor: Aaron S. Dumont



*Objective*. Endoscopic surgeries have been attempted in the field of lumbar decompression and fusion surgery in the past decade. Percutaneous endoscopic lumbar interbody fusion (PELIF) is a new-emerging technique taking advantages of an anatomical (Kambin's triangle) to achieve simultaneous decompression and fusion under endoscopic visualization. The purpose of this study is to evaluate the feasibility and safety of PELIF technique with general anesthesia and neuromonitoring. *Methods*. The authors present the details of PELIF technique with general anesthesia and neuromonitoring. The first 7 consecutive patients treated with minimum of 2 year's follow-up were included. Clinical outcomes were assessed by visual analog scale (VAS) for back and leg pain, Oswestry Disability Index (ODI) scores, and the Short Form-36 health survey questionnaire (SF-36) in the immediate preoperative period and during the follow-up period. *Results*. All patients underwent single-level PELIF surgery successfully and without conversion to open surgery. The average age was 56.0±13.0 years. All patients had Grade I degenerative/isthmic spondylolisthesis and 4 patients coexisted with disc herniation. The mean operative time was 167.5±30.9 minutes, and intraoperative blood loss was 70.0±24.5 ml. Postoperative drainage volume was 24.5±18.3 ml. The differences in the VAS scores for low back pain and leg pain between preoperative and follow-up were significant ($P<0.05$). The SF-36 Physical Component Summary (PCS) improved from 38.83±4.17 to 55.67±2.58 ($P<0.001$). The SF-36 Mental Component Summary (MCS) improved from 43.83±3.13 to 57.50±5.36 ($P=0.001$). The ODI score improvement rate was 33.7±3.7 %. All cases demonstrated radiopaque graft in the intervertebral disc space consistent with solid arthrodesis. *Conclusions*. PELIF technique seems to be a promising surgical technique for selected appropriate patients, with the minimal invasive advantages in decreased blood, shortage of ambulation time, and hospital stay, compared with MIS-TLIF. Because of limited Kambin's triangle space and the exiting nerve root nearby, PELIF is still a challenging technique. Future advancement and development in instrument and cage design are vital for application and popularization of this technique. Prospective, randomized, controlled studies with large sample size on PELIF technique are still needed to prove its safety, efficacy, and minimal invasive advantages.

## 1. Introduction

Conventional open posterior fusion surgery of the lumbar spine, though addressing the pathology adequately, may—depending on significant surgical destruction of posterior muscular-ligamentous complex—lead to muscular atrophy, postoperative back pain, and functional disability [1–4]. Therefore, several factors which include, but are not limited to, the desire to minimize complications and hospitalization; the desire to facilitate an early return to productive hospitalization; the desire for elderly patients to return to active premorbid status; and the desire to decrease the cost of medical care have combined to facilitate the paradigm shift from open to minimally invasive spine surgery (MIS) [5, 6].

Currently, there are many types of MIS lumbar fusion surgery, including transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), extreme lateral lumbar interbody fusion (XLIF), and posterior lumbar interbody fusion (PLIF) [2, 7]. All these procedures, though sharing the label of MIS, have different attributes in terms of

distraction of the normal anatomic structures; accessibility to the different levels of the spine [8]. The search for newer surgical methods to achieve the goals of minimally invasive surgery is essential.

Recently, endoscopic surgeries have been attempted in the field of lumbar decompression and fusion surgery [8–13]. Some of these techniques [9–11] are evolved from typical MIS-TLIF technique using smaller tubular retractor through wilts plane and endoscopy-assistance. In this study, we will mainly focus on percutaneous endoscopic lumbar interbody fusion technique (PELIF) based on full-endoscopic technique through Kambin's triangle, with a similar surgical access and manipulation as percutaneous endoscopic discectomy (PELD). This technique takes advantages of an anatomical corridor that allows for both decompression of the traversing and exiting nerve roots and approach to the interbody space in order to achieve simultaneous decompression and fusion under full-endoscopic visualization [14]. Meanwhile, the minimal invasive nature of this procedure may even allow surgery be performed without general anesthesia which might be great benefit decreasing anesthetic risk for elder patients [10]. The purpose of this article was to demonstrate the surgical technique of PELIF and share preliminary clinical experience.

## 2. Methods

This study is a retrospective analysis of a consecutive case series involving patients treated with endoscopic single-level PELIF at a single institution. All the medical records were anonymous, and no patient information was extracted except for research intention. All patients had Grade I degenerative/isthmic spondylolisthesis and 4 patients coexisted with disc herniation. A total 7 patients underwent follow-up for more than 30 months. Demographic characteristics, diagnosis, operation time, blood loss, drainage volume, time to ambulation, postoperative hospitalization days, and perioperative complications were evaluated. Clinical outcomes such as visual analog scale (VAS), Oswestry Disability Index (ODI) score, and the Short Form-36 health survey questionnaire (SF-36) were assessed before and after therapy. Postoperative complications and symptom recurrence requiring reoperation were assessed through review of medical record documentation and/or telephone interviews with patients. Fusion was considered to have occurred if the trabecular bone had been bridged, as seen on a postoperative CT scan.

*2.1. Surgical Management and Technique.* The patient is placed in prone position and the C-arm should be placed on the contralateral side of PELIF access. The patient's position on the table was adjusted to facilitate the disk approach, especially at level L5-S1, by increasing forward hip flexion but avoiding a kyphotic correction of the lumbar lordosis. In this case series, the authors used a percutaneous endoscopic technique for interbody fusion combined with screw fixation with general anesthesia and neuromonitoring. Lower extremity somatosensory evoked potential, transcranial electrical stimulation motor evoked potential, and spontaneous electromyography (EMG) was used to monitor nerve root function. The PELIF® O-Cage (Joimax GmbH, Germany) used in this procedure consists of an MRI-compatible titanium alloy (Ti6Al4V ELI) with osteoconductive surface which forms a base for optimal cell growth. The diamond cell structure increases the cage surface area and leads to optimal bony ingrowth. It is necessary to mention that PELIF® O-Cage is not designed as a "stand-alone" implant. The fusion should always be accompanied by posterior fixation of percutaneous pedicle screws and/or transarticular screws.

Traditional transforaminal puncture of an 18G needle is carried out with the entry point between 8 and 14 cm (10-12 cm at L4/5) lateral to the spinous process at a 40° to 60° angle and as parallel to the intervertebral disc space as possible (Figure 1(a)), Axial MRI and CT images can be useful to design the needle trajectory and calculate the distance of the skin entry point away from the midline. The 18G needle is advanced into the intervertebral disc space; the style is removed; and a 0.8 mm guide wire is inserted through the cannula. Subsequent tissue dilation and bone resection by subsequent reamers is performed up to the diameter of the TESSYS® working tube as traditional PELD procedure (Figure 1(b)). Neurological decompression and optional foraminoplasty by bone drill/endoscopic burr can be performed if needed (Figure 1(c)). The annulus is opened and a primary disc removal and nerve root decompression is performed under endoscopic views (Figure 1(d)). Appropriate position of working tube insertion was confirmed with anteroposterior and lateral X-ray views (Figures 1(e) and 1(f)).

The TESSYS® working tube is withdrawn, with a flexible 2.0 mm guide wire which is placed in the disc space instead. All instruments as well as the O-Cage itself can be perfectly positioned utilizing this guide wire. Perform the dilation with the PELIF® dilators until the desired diameter of the working tube (15 or 18 mm diameter) is achieved. The working tube is advanced over the dilators with a twisting motion counterclockwise until bone contact with the vertebral bodies. Subsequently, the working tube is anchored with a clockwise rotation onto the vertebrae and into the soft tissue (Figures 2(a) and 2(b)). The dilators are removed from the working tube. Placement of the endoscope adapter on the working tube in order to further remove intervertebral disc tissues under endoscopic view. If necessary, expanding the access using the bone drills (7.5 mm and 8.5 mm) to intervertebral disc space is extended to enable easier implantation of the cage. The raspatory is positioned between the end plates by using the 2.0 mm wire as a guide. The raspatories with different size are used sequentially for preparing the end plates by repeated rotation for at least 90°. The raspatories are also used for determining implant size under fluoroscopic control (Figures 2(c) and 2(d)). After fusion site preparation adequately, autogenous bone graft from superior articular process and commercial cancellous bone allograft was placed anteriorly and contralateral to the annulotomy within the interbody space through funnel-shaped bone graft device and the nerve root was again examined to ensure adequate decompression. Up to 35° degrees of cage angulation can be

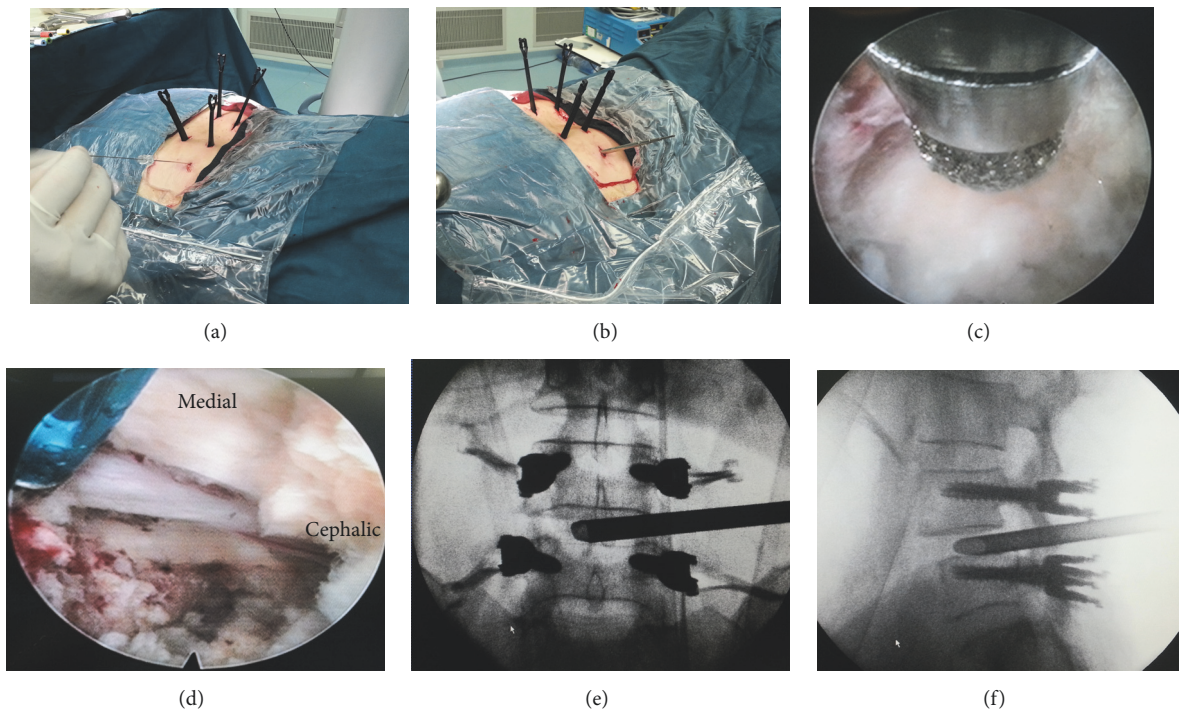



Figure 1: (a) Percutaneous transforaminal puncture into disk after percutaneous pedicle screw fixation. (b) Sequential dilation. (c) Optional foraminoplasty and expansion of the safety triangle by bone drill under endoscopic views. (d) Neurological decompression and initial endplate preparation in endoscopic view. (e) and (f) Working tube insertion in anteroposterior and lateral X-ray views.

achieved by adjusted the distal knob of insertion instrument to ease the cage placement. The cage is then introduced into the intervertebral disc space trough the working tube by gently tapping on the back of the instrument handle under X-ray control, ideally with the 2.0 mm guide wire kept in place. Neurological feedback from neuromonitoring should be carefully watched during this section. Release the cage from connected instruments when it is in appropriate position (Figures 2(e) and 2(f)).

Check the implant position, the working tube is removed by turning it counterclockwise. (Figures 2(g) and 2(h)) Percutaneous pedicle screws are then finally compressed and locked. After all instruments were removed, a subfascial hemovac is inserted and direct closure of the skin was done. Postoperative management is similar with MIS-TLIF surgery, while earlier ambulation in the same day of surgery is encouraged and permitted with lumbar orthosis because of less bony removal and soft tissues injury [15, 16]. Drainage catheter is suggested in some studies to prevent postoperative hematoma because pressure of saline irrigation may lead the surgeon to overlook the potential epidural bleeding [12]. The patients are normally discharged 1 or 2 days after the surgery.

*2.2. Statistical Analysis.* The paired t test was performed for the preoperative and follow-up parameters (VAS, ODI, SF-PCS, and SF-MCS). The descriptive assessments and analytical statistics were performed depending on the group characteristics with SPSS (version 21.0, SPSS, Chicago, IL, USA). A positive significance was defined as probability of less than 0.05 for two sides.

## 3. Results

The demographic and baseline characteristics of the enrolled patients are shown in Table 1. The average age was 56.0±13.0 years (range 33-72 years). All patients had Grade I degenerative/isthmic spondylolisthesis and 4 patients coexisted with disc herniation. All patients underwent a single-level PELIF surgery successfully and without conversion to open surgery. Neurologic improvements were evident after surgery and persisted during the follow-up period. The mean operative time was 167.5±30.9 minutes (range 135-220 minutes), and intraoperative blood loss was 70.0±24.5 ml (rang 50-100 ml). Postoperative drainage volume was 24.5±18.3 ml (range 5-50 ml). The mean length of time to ambulation was 1.2±0.6 nights.

The preoperative clinical outcome assessments were respectively compared with postoperative 1 year and 2-year follow-up. All patients were tracked with 35.1±3.0 months mean follow-up (range 31.5-38.1 months). The differences in the VAS scores for low back pain and leg pain between preoperative and 1/2-year follow-up were significant ($P<0.05$). The SF-36 Physical Component Summary (PCS) improved from 38.83±4.17 to 55.67±2.58 ($P<0.001$). The SF-36 Mental Component Summary (MCS) improved from 43.83±3.13 to 57.50±5.36 ($P=0.001$). The ODI score improvement rate was 33.7±3.7 %. (Table 2)

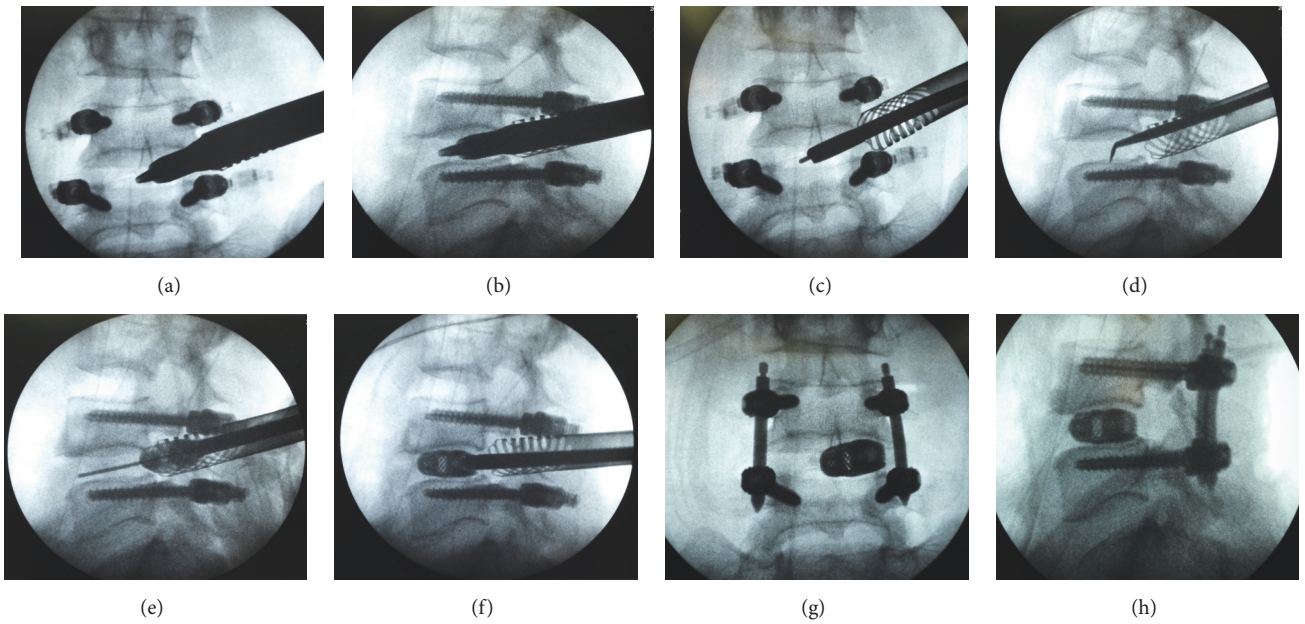



Figure 2: (a) and (b) Performing the dilation with the PELIF dilators until the desired diameter of the working tube. (c) and (d) Further removing intervertebral disc tissues and adequately endplate preparation. (e) and (f) Utilizing the guide wire to ease the cage placement under X-ray control. (g) and (h) Identification of the implant position by anteroposterior and lateral views.

Table 1: Clinical summary of enrolled patients.

| Case No. | Sex/ Age (y) | Duration of Disease (months) | Operation Time (min) | Blood Loss (ml) | Drainage Volume (ml) | Follow-up Time (months) | Operative Level |
|---|---|---|---|---|---|---|---|
| 1 | M/57 | 6 | 220 | 100 | 40 | 38.1 | L4/5 |
| 2 | F/59 | 36 | 165 | 100 | 50 | 37.9 | L4/5 |
| 3 | F/33 | 24 | 145 | 50 | 12 | 37.5 | L4/5 |
| 4 | F/53 | 120 | 185 | 50 | 5 | 33.0 | L4/5 |
| 5 | M/62 | 84 | 135 | 50 | 10 | 32.7 | L4/5 |
| 6 | M/72 | 36 | 155 | 70 | 30 | 31.5 | L4/5 |

Radiographic imaging included flexion-extension radiographs and CT images were taken at 1, 12, and 24 months after surgery (Figure 3). All cases demonstrated radiopaque graft in the intervertebral disc space consistent with solid arthrodesis. There were no clinical or radiographic signs of nonunion. And there were no cases with perioperative and postoperative complication, such as dural tears, infection, or implant loosening. Revision surgery was not required in any patient.

## 4. Discussion

PELIF technique is a new-emerging technique evolved from PELD surgery in the recent decade; PELIF conducts lumbar interbody fusion through percutaneous transforaminal endoscopic access in Kambin's triangle like traditional PELD techniques [17]. PELIF were performed through sequential dilatation in soft tissues and very few bone removals compared with MIS-TLIF and theoretically offer advantages of less invasive, decreased blood loss, shorter patient recovery time, and the possibility of performing the surgery without anesthesia [8, 10, 16]. In this study, we demonstrated the feasibility and safety of PELIF technique with general anesthesia and shared clinical experiences with 2-year follow-up. Under general anesthesia, we found very little nerve distraction according to the method of progressive dilatation. From the anatomical perspective, the exiting root forms the hypotenuse of the working zone. The mean shortest distance between the root and facet surface was reported less than 2 mm at the upper disc margin level and less than 7 mm at the lower disc margin level [18]. Therefore, partial facetectomy of superior articular process is an essential step to provide us the sufficient space for PELIF procedures and eliminate exiting root injury [14]. So local anesthesia with/without sedation, low-dose epidural anesthesia, would be better choice for standard PELIF technique. Possibility of local anesthesia offers additional benefit for elder patients especially with systemic diseases.

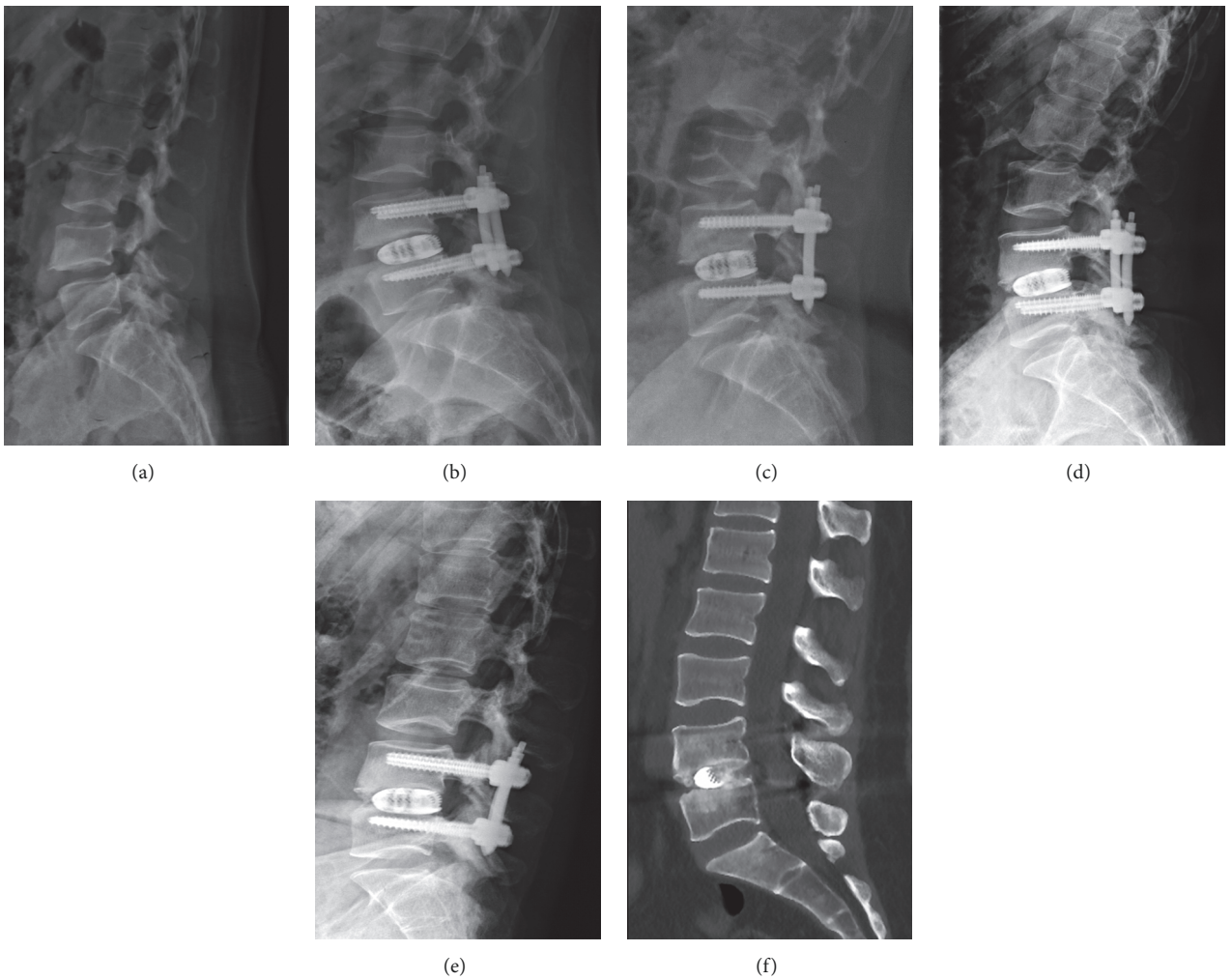


Figure 3: (a) Preoperative lateral radiograph showing isthmic spondylolisthesis. (b) and (c) Lateral radiograph at 1 and 12 months postoperative. (d) and (e) Extension and flexion lateral X-rays at two-years follow-up. (f) Sagittal CT image obtained 2 years postoperatively showing interbody fusion.

*4.1. Indications of PELIF Include the Following.* Single-level fusion surgery from L3–4 to L5–S1 is initially recommended. Indications of PELIF were usually advised for degenerative disc disease, degenerative/isthmic spondylolisthesis, and spinal stenosis with instability. Postoperative instability or fail back syndrome (FBSS) to the lumbar spine is also an indication.

*4.2. Contraindications Include, but Are Not Limited to the Following.* Any condition which eliminates the potential profile of a spinal implant is relative contraindications, such as congenital abnormalities, bone resorption, osteopenia, poor bone quality and osteoporosis, infection, spondylodiscitis or signs of local inflammation, vertebral fractures, extremely narrow Kambin's triangle due to collapsed foramen/intervertebral disc height, or neurological abnormity; severe central stenosis could not be satisfactorily decompressed under PELD, high-grade spondylolisthesis.

Although only a few studies with small sample size have reported surgical technique and clinical results of PELIF, nearly all of the existent clinical studies [8, 10–13, 15, 16, 19] reported significant minimal invasive advantages superior to MIS-TLIF (e.g., smaller incision from 7-15mm, very early standing and ambulation at the same day of surgery with no additional care, and a significant reduced hospital stay). In contrast, posterior MIS-TLIF was reported to need an incision about 30 mm and splitting of paravertebral muscles; also the time after surgery until ambulation and hospital discharge may be up to 3.2 days and 9.3 days on average, respectively [20]. In the present study, the mean operative time was 167.5 minutes, and intraoperative blood loss was 70.0 ml. Postoperative drainage volume was just 24.5±18.3 ml. The mean length of time to ambulation was 1.2±0.6 nights. Through the expanded safety triangle zone approach, we can expose only the exiting nerve root to perform interbody fusion without intra-abdominal dissection or exposing central dura and traversing nerve root. No general complications

Table 2: Preoperative, follow-up VAS, ODI, and SF-36 scores.

| Characteristics | Value | P value |
|---|---|---|
| Lower back pain VAS, mean ± SD | | |
| Preoperative | 6.17±0.75 | - |
| Postoperative 1 year | 0.83±0.75 | <0.001* |
| Postoperative 2 years | 0.67±0.52 | <0.001# |
| Lower extremity pain VAS, mean ±SD | | |
| Preoperative | 5.33±1.97 | - |
| Postoperative 1 year | 0.33±0.52 | 0.004* |
| Postoperative 2 years | 0.17±0.41 | 0.002# |
| SF-36 PCS, mean ± SD | | |
| Preoperative | 38.83±4.17 | - |
| Postoperative 1 year | 51.33±3.20 | <0.001* |
| Postoperative 2 years | 55.67±2.58 | <0.001# |
| SF-36 MCS, mean ± SD | | |
| Preoperative | 43.83±3.13 | - |
| Postoperative 1 year | 56.33±6.83 | 0.009* |
| Postoperative 2 years | 57.50±5.36 | 0.001# |
| ODI score, mean ± SD | | |
| Preoperative | 44.83±4.75 | - |
| Postoperative 1 year | 14.50±8.09 | <0.001* |
| Postoperative 2 years | 11.17±4.31 | <0.001# |

∗ $p<0.05$, postoperative 1 year compared with preoperative.
# $p<0.05$, postoperative 2 years compared with preoperative.
VAS, visual analog scale; MCS, Mental Component Score; PCS, Physical Component Score; SF-36, Short Form-36 Health Surgery Questionnaire.

include DVT and pulmonary embolism was reported. Other complications such as CSF leak and postoperative hematoma were seldom observed [8, 9, 21]. In our clinical practice, perioperative complication was also not observed. And the anesthesiologic risk may be eliminated; even local anesthesia is optional [19].

In preliminary practice of PELIF, stand-alone B-Twin expandable spacer is a common option of disc spacers [19, 20]. The small size of B-Twin expandable spacer facilitated its placement in a very small incision and working tube with minimal risk of neurological impairment. Disc height restore was satisfactory from preoperative 8.3±1.6 mm (range, 5.2–11.5) improved to 11.4±1.8mm (range, 8.8–14.7) in early postoperative period. However, excellent or good results were only obtained in only 72.2% of the patients which the author personally contributes it may because of a small sample size. Other literatures of percutaneous LIF studies using the B-Twin expandable spacer reported satisfactory results, but radiological results including disc space subsidence in all and breakage of implant limbs in some patients make the stand-alone application of the expandable spacer (without any posterior fixation) debatable [22]. In our study, the unexpandable O-Cage (Joimax GmbH, Germany) which consists of an MRI-compatible titanium alloy (Ti6Al4V ELI) with osteoconductive surface forms a base for optimal cell growth was used in the PELIF surgery. O-Cage is not designed as a "stand-alone" implant, so fusion should always be accompanied by posterior fixation of percutaneous pedicle screws or transarticular screws. As O-Cage is not an expandable cage, we just cautiously selected the appropriate patients except for extremely small Kambin's triangle area due to collapsed foramen/intervertebral disc height, severe central stenosis which could not be satisfactorily decompressed under PELD.

In 2013, Frederic Jacquot reported [23] the largest case series of PELIF with 57 patients and gave negative opinion for this technique. The author utilized rigid cage placement with stand-alone cages in 46 cases and contemporary posterior plate fixation in 11 patients. While extremely high cage migration and reoperation rate was reported in this trial, with 2 asymptomatic migration of the cages occurred required no further operation, 13 symptomatic migration (22.8 %), requiring a conventional secondary reoperation, after a mean delay of eight months (range three to 36 months) with no neurological deficit. Meanwhile, eight additional patients (14 %) suffered from postoperative paresis and painful syndromes. The author also mentioned that rest patient without above complications had excellent results following a very fast recovery and a very short hospital stay. The author concluded that PELIF technique is not recommended in its current state because of extremely high complication rate except technical improvements despite a prominent fast recovery. We suspected that an extremely high complication rate of cage migration and postoperative paresis

compared with other PELIF reports may be related to the following intraoperative factors although detailed surgical procedures were not given: inadequate disc preparation due to very fast surgery and calcium phosphate substitute filled in cages with no autograft or other alternatives prefilled in disc space before cage insertion mentioned, nonexpandable stand-alone cages were used and no foraminoplasty was reported to employ in this clinical trial, in addition, a considerable lager number of patients were operated in upper lumbar segment with anatomical narrow Kambin's triangle. In this study, all patients underwent a single-level PELIF surgery successfully and without conversion to open surgery. Neurologic improvements were evident after surgery and persisted during the follow-up period. Two-year follow-up showed significant improvement in VAS, ODI score, SF-36 PCS, and MCS, which were consistent with the previous studies [10]. Fusion was obtained in all cases with radiopaque graft in disc space consistent with solid arthrodesis and no clinical or radiographic signs of nonunion.

A thorough understanding of foraminal anatomy is fundamental for considering how to safely access the disc space and what shapes and sizes of interbody implants are feasible for use in the foramen [14]. Considering stand-alone cages may increase the risk of migration and/or subsidence, when compared to cage fusion with additional pedicle screw fixation, some of the recent studies trended to applied additional percutaneous pedicle screw and/or transarticular screw [16]. Self-expandable cage design seems to be better option for PELIF technique as related literature described. Firstly, self-expandable cage which has smaller initial size facilitates cage insertion and reduces possible neurological invasion [19, 24]. Study of Rudolf Morgenstern indicated [16] improvement of leg pain was slightly higher in patients treated with the expandable cage than in patients treated with the PEEK cage. Other possible advantages were also mentioned as follows: expandable cages allow indirect neural decompression and additional foraminal expansion by restoring intervertebral height; immediate stability to the fixation construct was also enhanced. In cases of spondylolisthesis, percutaneous expanded interbody implants may offer convenient distraction and reduction.

Exiting root injury presented as postoperative paresis and radical pain is specific and common complication for pTLIF technique similar but more common than PELD because more occupation of transforaminal space due to cage insertion. Rudolf Morgenstern [16] suggested neuromonitoring to be routinely performed in general anesthesia with somatosensory evoked potentials (SEP) and motor evoked potentials (MEP) be employed during the whole surgical procedure to monitor all involved peripheral nerves. Additional nerve stimulation was also performed to ensure that nerve roots were not compromised at special conditions such as cage insertion. A bevel-end working tube should be use and careful rotation of the bevel may be helpful for protection of the exiting root during procedure. Foraminoplasty is always necessary especially at the level of L5-S1 or any situation needed [19, 21]. In addition, more reliability and efficiency endoscopic approaches which access the inferior disc space-superior endplate junction at the medial wall of the pedicle can achieves exponential ($\pi$r2) increases in disc space dilation for interbody implant placement and decrease nerve root distraction [14].

Despite all the benefit above mentioned, PELIF seems to be an immature and high-demanding and controversial procedure with limited indication and possible specific complications. Very narrow space of Kambin's triangle cause technique difficulties for thorough disc preparation and safe cage insertion, leading to complications like exiting nerve root injury, nonunion, or cage migration. Other obstacles included steep learning curve, need for rich full-endoscopic experience, lack of autograft due to few bone removal, excessive radiation exposure increases fear of for the patient, and the surgical team. Finally, it is essential to point out that all of the related several studies on PELIF technique were preliminary retrospective, uncontrolled trails with relatively small sample size, which make us incapable to give a comprehensive and definitive assess on it at present.

## 5. Conclusions

Present PELIF technique with the titanium alloy spacer seems to be a promising surgical technique for selected appropriate patients. The clinical results of attempt in PELIF technique support the minimal invasive advantages in decreased blood, shortage of ambulation time, and hospital stay, compared with MIS-TLIF. Steep learning curve with rich previous PELD experience needed. Because of limited Kambin's triangle space, PELIF technique is still a challenging procedure. Future advancement and development in instrument and cage design are vital for application and popularization of this technique. Prospective, randomized, controlled studies with large sample size on PELIF technique are still needed to prove its safety, efficacy, and minimal invasive advantages.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

This research was supported by the clinical research project of the Second Affiliated Hospital of Army Medical University (Grant no. 2015YLC22).

## References

[1] N. E. Epstein, "How often is minimally invasive minimally effective: what are the complication rates for minimally invasive surgery?" *Surgical Neurology*, vol. 70, no. 4, pp. 386–388, 2008.

[2] J. H. Oppenheimer, I. DeCastro, and D. E. McDonnell, "Minimally invasive spine technology and minimally invasive spine surgery: a historical review," *Neurosurgical Focus*, vol. 27, no. 3, p. E9, 2009.

[3] J. A. Rihn, R. Patel, J. Makda et al., "Complications associated with single-level transforaminal lumbar interbody fusion," *The Spine Journal*, vol. 9, no. 8, pp. 623–629, 2009.

[4] C. L. Goldstein, K. Macwan, K. Sundararajan, and Y. R. Rampersaud, "Perioperative outcomes and adverse events of minimally invasive versus open posterior lumbar fusion: meta-analysis and systematic review," *Journal of Neurosurgery: Spine*, vol. 24, no. 3, pp. 416–427, 2016.

[5] K. P. J. A. H. R. J. Mobbs, "Cost–utility of minimally invasive versus open transforaminal lumbar interbody fusion: systematic review and economic evaluation," *European Spine Journal*, 2015.

[6] C. L. Goldstein, F. M. Phillips, and Y. R. Rampersaud, "Comparative effectiveness and economic evaluations of open versus minimally invasive posterior or transforaminal lumbar interbody fusion: a systematic review," *The Spine Journal*, vol. 41, no. 8, pp. s74–s89, 2016.

[7] A. J. Schoenfeld, "Minimally invasive lumbar fusion," *Seminars in Spine Surgery*, vol. 23, no. 4, pp. 235–241, 2011.

[8] S. G. Osman, "Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report," *International Journal of Spine Surgery*, vol. 6, no. 1, pp. 157–166, 2012.

[9] Y.-T. Wang, X.-T. Wu, H. Chen, and C. Wang, "Endoscopy-assisted posterior lumbar interbody fusion in a single segment," *Journal of Clinical Neuroscience*, vol. 21, no. 2, pp. 287–292, 2014.

[10] M. Y. Wang and J. Grossman, "Endoscopic minimally invasive transforaminal interbody fusion without general anesthesia: initial clinical experience with 1-year follow-up," *Neurosurgical Focus*, vol. 40, no. 2, p. E13, 2016.

[11] E.-X. He, J. Guo, Q.-J. Ling, Z.-X. Yin, Y. Wang, and M. Li, "Application of a narrow-surface cage in full endoscopic minimally invasive transforaminal lumbar interbody fusion," *International Journal of Surgery*, vol. 42, pp. 83–89, 2017.

[12] D. H. Heo, S. K. Son, J. H. Eum, and C. K. Park, "Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: Technical note and preliminary clinical results," *Neurosurgical Focus*, vol. 43, no. 2, p. E8, 2017.

[13] M. S. Youn, J. K. Shin, T. S. Goh, and J. S. Lee, "Full endoscopic lumbar interbody fusion (FELIF): technical note," *European Spine Journal*, pp. 1–7, 2018.

[14] M. Hardenbrook, S. Lombardo, M. C. Wilson, and A. E. Telfeian, "The anatomic rationale for transforaminal endoscopic interbody fusion: A cadaveric analysis," *Neurosurgical Focus*, vol. 40, no. 2, p. E12, 2016.

[15] R. Morgenstern, C. Morgenstern, R. Jané, and S.-H. Lee, "Usefulness of an expandable interbody spacer for the treatment of foraminal stenosis in extremely collapsed disks: preliminary clinical experience with endoscopic posterolateral transforaminal approach," *Journal of Spinal Disorders & Techniques*, vol. 24, no. 8, pp. 485–491, 2011.

[16] R. Morgenstern and C. Morgenstern, "Percutaneous Transforaminal lumbar interbody fusion (pTLIF) with a posterolateral approach for the treatment of denegerative disk disease: feasibility and preliminary results," *International Journal of Spine Surgery*, vol. 9, p. 41, 2015.

[17] S. R. Mirkovic, D. G. Schwartz, and K. D. Glazier, "Anatomic considerations in lumbar posterolateral percutaneous procedures," *The Spine Journal*, vol. 20, no. 18, pp. 1965–1971, 1995.

[18] I. Choi, J.-O. Ahn, W.-S. So, S.-J. Lee, I.-J. Choi, and H. Kim, "Exiting root injury in transforaminal endoscopic discectomy: preoperative image considerations for safety," *European Spine Journal*, vol. 22, no. 11, pp. 2481–2487, 2013.

[19] S. H. Lee, H. Y. Erken, and J. Bae, "Percutaneous transforaminal endoscopic lumbar interbody fusion: clinical and radiological results of mean 46-month follow-up," *BioMed Research International*, vol. 2017, Article ID 3731983, 2017.

[20] F. Shunwu, Z. Xing, Z. Fengdong, and F. Xiangqian, "Minimally invasive transforaminal lumbar interbody fusion for the treatment of degenerative lumbar diseases," *Spine*, vol. 35, no. 17, pp. 1615–1620, 2010.

[21] J.-S. Kim, B. Jung, and S.-H. Lee, "Instrumented minimally invasive spinal-transforaminal lumbar interbody fusion (MIS-TLIF); minimum 5-years follow-up with clinical and radiologic outcomes," *Clinical Spine Surgery*, vol. 31, no. 6, pp. E302–E309, 2018.

[22] Y. Folman, S.-H. Lee, J. R. Silvera, and R. Gepstein, "Posterior lumbar interbody fusion for degenerative disc disease using a minimally invasive B-twin expandable spinal spacer: a multicenter study," *Journal of Spinal Disorders & Techniques*, vol. 16, no. 5, pp. 455–460, 2003.

[23] F. Jacquot and D. Gastambide, "Percutaneous endoscopic transforaminal lumbar interbody fusion: is it worth it?" *International Orthopaedics*, vol. 37, no. 8, pp. 1507–1510, 2013.

[24] L. Xiao, D. Xiong, Q. Zhang et al., "Percutaneous posterior-lateral lumbar interbody fusion for degenerative disc disease using a B-Twin expandable spinal spacer," *European Spine Journal*, vol. 19, no. 2, pp. 325–330, 2010.

Hindawi
BioMed Research International
Volume 2018, Article ID 9073460, 8 pages
https://doi.org/10.1155/2018/9073460

*Review Article*

# A Comparison of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Lumbar Disc Herniation in the Korean: A Meta-Analysis

**Manyoung Kim**,[1] **Sol Lee**,[2] **Hyeun-Sung Kim**,[3] **Sangyoon Park**,[4] **Sang-Yeup Shim**,[4] **and Dong-Ju Lim**[4]

[1]*Department of Orthopedic Surgery, Gangnam Nanoori Hospital, 731 Eonju-ro, Gangnam-gu, Seoul 06048, Republic of Korea*
[2]*Department of Health Policy and Management, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul 02841, Republic of Korea*
[3]*Department of Neurosurgery, Gangnam Nanoori Hospital, 731 Eonju-ro, Gangnam-gu, Seoul 06048, Republic of Korea*
[4]*Department of Orthopedic Surgery, Sanggye Paik Hospital, Inje University College of Medicine, 1342 Dongil-ro, Nowon-gu, Seoul 01757, Republic of Korea*

Correspondence should be addressed to Dong-Ju Lim; scd25@paik.ac.kr

Received 6 June 2018; Accepted 31 July 2018; Published 7 August 2018

Academic Editor: William B. Rodgers



*Background.* Among the surgical methods for lumbar disc herniation, open lumbar microdiscectomy is considered the gold standard. Recently, percutaneous endoscopic lumbar discectomy is also commonly performed for lumbar disc herniation for its various strong points. *Objectives*. The present study aims to examine whether percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy show better results as surgical treatments for lumbar disc herniation in the Korean population. *Methods*. In the present meta-analysis, papers on Korean patients who underwent open lumbar microdiscectomy and percutaneous endoscopic lumbar discectomy were searched, both of which are surgical methods to treat lumbar disc herniation. The papers from 1973, when percutaneous endoscopic lumbar discectomy was first introduced, to March 2018 were searched at the databases of MEDLINE, EMBASE, PubMed, and Cochrane Library. *Results*. Seven papers with 1254 patients were selected. A comparison study revealed that percutaneous endoscopic lumbar discectomy had significantly better results than open lumbar microdiscectomy in the visual analogue pain scale at the final follow-up (leg: mean difference [MD]=-0.35; 95% confidence interval [CI]=-0.61, -0.09; p=0.009; back: MD=-0.79; 95% confidence interval [CI]=-1.42, -0.17; p=0.01), Oswestry Disability Index (MD=-2.12; 95% CI=-4.25, 0.01; p=0.05), operation time (MD=-23.06; 95% CI=-32.42, -13.70; p<0.00001), and hospital stay (MD=-4.64; 95% CI=-6.37, -2.90; p<0.00001). There were no statistical differences in the MacNab classification (odds ratio [OR]=1.02; 95% CI=0.71, 1.49; p=0.90), complication rate (OR=0.72; 95% CI=0.20, 2.62; p=0.62), recurrence rate (OR=0.83; 95% CI=0.50, 1.38; p=0.47), and reoperation rate (OR=1.45; 95% CI=0.89, 2.35; p=0.13). *Limitations*. All 7 papers used for the meta-analysis were non-RCTs. Some differences (type of surgery (primary or revisional), treatment options before the operation, follow-up period, etc.) existed depending on the selected paper, and the sample size was small as well. *Conclusion*. While percutaneous endoscopic lumbar discectomy showed better results than open lumbar microdiscectomy in some items, open lumbar microdiscectomy still showed good clinical results, and it is therefore reckoned that a randomized controlled trial with a large sample size would be required in the future to compare these two surgical methods.

## 1. Introduction

Among the surgical methods for lumbar disc herniation, open lumbar microdiscectomy (OLD) is considered the gold standard [1]. Lumbar disc herniation is a common cause of low back pain and radiating pain to the lower extremities [2] and conservative therapy can improve the symptoms in most cases. In 10-20% of these cases, pain continues despite conservative therapy, and surgical treatment is considered [3]. While OLD can rarely cause scar tissues around nerves,

damage to facet joints, and lumbar instability after the operation, it is widely performed as it shows good clinical results [4–7].

Recently, percutaneous endoscopic lumbar discectomy (PELD) is also commonly performed for lumbar disc herniation for its various strong points compared to OLD such as surgery under local anesthesia, less damage to surrounding muscles and bone structures, and fast patient recovery [8–12]. Indications were limited depending on the location and progression of lesions in early days [13, 14], but lately these limitations have been overcome owing to advances in technology and tools [9–12].

Nevertheless, it has not been clearly confirmed whether PELD, which had good results recently, is better than OLD, the gold standard, in Korean patients.

The purpose of this study is to determine through a meta-analysis whether PELD or OLD has better results as a surgical treatment for lumbar disc herniation in the Korean population.

## 2. Methods

*2.1. Literature Search Strategy.* Relevant studies were searched in MEDLINE, EMBASE, PubMed, and Cochrane Library. Retrieval time was from 1973, when PELD was first introduced, to March 2018. The papers were extracted using search keywords such as "lumbar disc herniation," "microdiscectomy," "percutaneous endoscopic lumbar discectomy," "intervertebral disc displacement," "transforaminal lumbar discectomy," "minimally invasive discectomy," and "interlaminar discectomy"; the researcher extracted only those studies conducted on humans, which were written in English.

*2.2. Inclusion Criteria and Exclusion Criteria.* Two authors (M Kim and S Lee) identified the titles and abstracts or both and summarized the data from the selected articles. The searched papers were selected based on the following criteria: (1) those which were either randomized or nonrandomized controlled trials, (2) those that had at least one significant result on Korean patients, and (3) those on patients who underwent PELD or OLD for lumbar disc herniation. The papers on those who had a combined surgery and lesions in more than one area and case reports, letters, and comments were excluded.

*2.3. Data Extraction.* The following data were extracted from the papers collected by two of the authors (M Kim and S Lee): (a) basic information such as the type of trial, follow-up period, type of surgery, sample size, and patient age and sex and (b) clinical results such as the visual analogue pain scale (VAS) score (leg and back), complication rate, recurrence rate, reoperation rate, hospital stay, operation time, MacNab classification, and Oswestry Disability Index (ODI).

*2.4. Quality Assessment.* All 7 collected papers were nonrandomized clinical trials, and the Newcastle-Ottawa Quality Assessment Scale (NOQAS) was used for quality assessment. Out of a possible 9 items, 3 of selection, comparability, and exposure or outcome account for 4, 2, and 3 points, respectively. Five points or more indicated a low risk of bias, while 4 or less indicated having a high risk of bias [15].

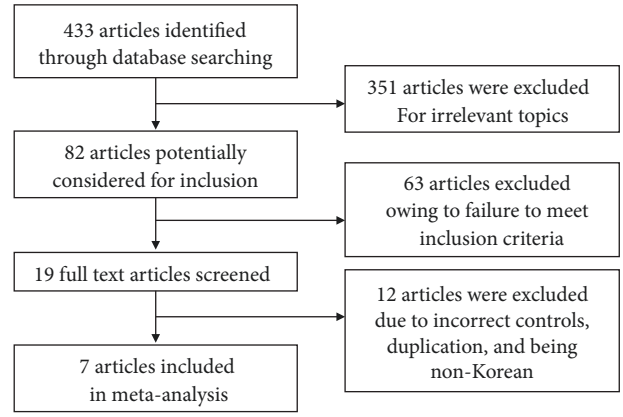



Figure 1: Flow diagram detailing study inclusion.

*2.5. Statistical Analysis.* The continuous variables (VAS, hospital stay, operation time, and ODI) were weighted with the number of patients, and the weighted average results were calculated. They were analyzed using standard deviations at a 95% confidence interval (CI). Meanwhile, the binary variables (complication rate, recurrence rate, reoperation rate, and MacNab score) were analyzed using the odds ratio (OR) at a 95% CI. I2 statistics were used to determine heterogeneity, and more than 50% was regarded as heterogeneous. The Review Manager software (version 5.3; The Cochrane Collaboration, Oxford, United Kingdom) was used as a statistical program for analysis.

## 3. Result

*3.1. Identification of Relevant Studies.* A total of 433 papers were searched, and 426 of them, which did not meet the selection criteria, were excluded. Figure 1 illustrates how the papers were selected, and the final 7 papers satisfied the inclusion criteria and were included in this study's analysis [11, 16–21].

*3.2. Study Characteristics and Quality Assessment.* The basic characteristics of the selected papers are presented in Table 1. All of the 7 selected papers were nonrandomized retrospective studies. The quality assessment results are provided in Table 2, and, except for one paper that scored 4 points in NOQAS, the other papers scored 5–7 points and showed good results in the quality assessment.

*3.3. Meta-Analysis Results*

*3.3.1. VAS Score at the Final Follow-Up.* Among the 7 papers, 5 presented the results of the VAS (leg), and 293 subjects were included in the analysis: 134 in the PELD group and 159 in the OLD group. The PELD group's average VAS was 2.04, while that of the OLD group was 2.47. The PELD group showed a significantly lower average VAS (leg) at the final follow-up than the OLD group (mean difference [MD]=-0.35;

Table 1: Baseline characteristics of included studies.

| Author and year | Study design | Number of patients (male/female) | | Patient age (years) | | Follow-up time (month) | |
|---|---|---|---|---|---|---|---|
| | | PELD | OLD | PELD | OLD | PELD | OLD |
| Jeong (2006) | Non-randomized retrospective comparative | 22(14/8) | 25(16/9) | 56.45±10.89 | 56±9.12 | 12 | 12 |
| Lee (2006) | Non-randomized retrospective comparative | 30(22/8) | 30(22/8) | 39.3(22-67) | 39.6(20-64) | 38.2(32-45) | 36.8(35-42) |
| Kim (2007) | Non-randomized retrospective comparative | 295(188/107) | 607(392/215) | 34.9(13-83) | 44.4(17-80) | 23.6(18-36) | 23.6(18-36) |
| Lee (2009) | Non-randomized retrospective comparative | 25(16/9) | 29(22/7) | 42.0±11.4 | 47.7±12.2 | 34.0±4.4 | 34.3±4.6 |
| Ahn (2016) | retrospective cohort | 32(32/0) | 34(34/0) | 22.41±1.68 | 22.18±1.51 | 13.69±1.26 | 13.41±1.02 |
| Choi (2016) | retrospective cohort | 20(14/6) | 23(13/10) | 33.9±11.1 | 38±11.6 | 27.5±5.7 | 27.5±5.7 |
| Lee (2017) | Non-randomized retrospective comparative | 35(25/10) | 48(30/18) | 50.20±12.87 | 50.13±11.56 | 24.17±11.83 | 23.65±7.94 |

Table 2: Risk of bias assessment of the nonrandomized studies.

| Studies | Selection | Comparability | Exposure | Total Quality score |
|---|---|---|---|---|
| Jeong (2006) | 2 | 2 | 1 | 5 |
| Lee (2006) | 2 | 2 | 3 | 7 |
| Kim (2007) | 2 | 1 | 1 | 4 |
| Lee (2009) | 2 | 2 | 1 | 5 |
| Lee (2017) | 2 | 2 | 2 | 6 |
| Ahn (2016) | 2 | 2 | 2 | 6 |
| Choi (2016) | 2 | 2 | 1 | 5 |

95% CI=-0.61, -0.09; p=0.009) (Figure 2). No heterogeneity existed between individual studies included in the analysis ($I^2$=0%, p=0.91).

Among the 7 papers, 4 presented the results of the Visual VAS (back), and 246 subjects were included in the analysis: 112 in the PELD group and 134 in the OLD group. The PELD group's average VAS (back) was 2.40, while that of the OLD group was 3.14. The PELD group showed a significantly lower average VAS (back) at the final follow-up than the OLD group (MD=-0.79; 95% CI=-1.42, -0.17; p=0.01) (Figure 3). Heterogeneity existed between individual studies included in the analysis ($I^2$=85%, p=0.0001).

*3.3.2. MacNab Classification at the Final Follow-Up.* Among the 7 papers, 3 presented the results of the MacNab score (success rate), and 1,009 subjects were included in the analysis: 347 in the PELD group and 662 in the OLD group. Those who answered with excellent or good were defined as successful, and 298 among the 347 subjects in the PELD group answered with successful in the MacNab criteria. Among the 662 subjects in the OLD group, 564 answered with successful. There were no significant differences in the average MacNab score (success rate) between the PELD and OLD groups (odds ratio [OR]=1.02; 95% CI=0.71, 1.49; p=0.90) (Figure 4). There was no heterogeneity between individual studies included in the analysis ($I^2$=0%, p=0.72).

*3.3.3. ODI.* Among the 7 papers, 4 presented the results of the ODI, and 246 subjects were included in the analysis: 112 in the PELD group and 134 in the OLD group. The PELD group's average ODI was 14.54%, while that of the OLD group was 16.52%. The PELD group showed a significantly lower average ODI at the final follow-up than the OLD group (MD=-2.12; 95% CI=-4.25, 0.01; p=0.05) (Figure 5). Heterogeneity existed between individual studies included in the analysis ($I^2$=67%, p=0.03).

*3.3.4. Complication Rate.* Among the 7 papers, 4 presented the results of the complication rate, and 1,105 subjects were included in the analysis: 387 in the PELD group and 718 in the OLD group. Fourteen subjects in the PELD group and 26 subjects in the OLD group had complications. There were no significant differences in the complication rate between the PELD and OLD groups (OR=0.72; 95% CI=0.20, 2.62;

| Study or Subgroup | PELD Mean | PELD SD | PELD Total | OLD Mean | OLD SD | OLD Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn (2016) | 1.29 | 2.27 | 22 | 1.7 | 1.72 | 25 | 5.0% | -0.41 [-1.57, 0.75] |
| Choi (2016) | 2.9 | 2.5 | 25 | 3.5 | 3.1 | 29 | 3.1% | -0.60 [-2.09, 0.89] |
| Jeong (2006) | 2.06 | 0.84 | 32 | 2.32 | 1.01 | 34 | 34.2% | -0.26 [-0.71, 0.19] |
| Lee (2009) | 1.7 | 1.2 | 20 | 2.3 | 0.8 | 23 | 17.8% | -0.60 [-1.22, 0.02] |
| Lee (2017) | 2.23 | 0.65 | 35 | 2.52 | 1.25 | 48 | 39.9% | -0.29 [-0.70, 0.12] |
| **Total (95% CI)** | | | **134** | | | **159** | **100.0%** | **-0.35 [-0.61, -0.09]** |

Heterogeneity: Tau$^2$=0.00; Chi$^2$=0.98, df=4 (P=0.91); I$^2$=0%
Test for overall effect: Z=2.63 (P=0.009)

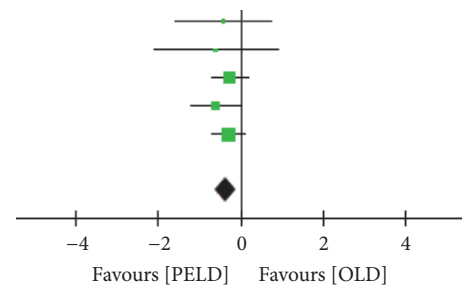



Figure 2: Forest plot of comparison: PELD versus OLD; outcome: 1-1 for VAS (leg), final follow-up.

| Study or Subgroup | PELD Mean | PELD SD | PELD Total | OLD Mean | OLD SD | OLD Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn (2016) | 2.5 | 0.62 | 32 | 2.91 | 0.67 | 34 | 30.1% | -0.41 [-1.57, 0.75] |
| Choi (2016) | 2 | 0.6 | 20 | 3.7 | 1 | 23 | 27.2% | -0.60 [-2.09, 0.89] |
| Lee (2009) | 2.9 | 2.4 | 25 | 3.1 | 2.5 | 29 | 13.5% | -0.20 [-1.51, 1.11] |
| Lee (2017) | 2.23 | 0.65 | 35 | 2.85 | 1.09 | 48 | 29.2% | -0.62 [-1.00, -0.24] |
| **Total (95% CI)** | | | **112** | | | **134** | **100.0%** | **-0.79 [-1.42, -0.17]** |

Heterogeneity: Tau$^2$=0.31; Chi$^2$=20.31, df=3 (P=0.0001); I$^2$=85%
Test for overall effect: Z=2.48 (P=0.01)

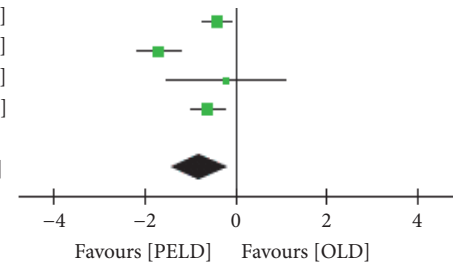



Figure 3: Forest plot of comparison: PELD versus OLD; outcome: 1-2 for VAS (back), final follow-up.

| Study or Subgroup | PELD Events | PELD Total | OLD Events | OLD Total | Weight | Odds Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Jeong (2006) | 19 | 22 | 20 | 25 | 5.7% | 1.58 [0.33, 7.56] |
| Kim (2007) | 250 | 295 | 516 | 607 | 92.0% | 0.98 [0.66, 1.44] |
| Lee (2006) | 29 | 30 | 28 | 30 | 2.3% | 2.07 [0.18, 24.15] |
| **Total (95% CI)** | | **347** | | **662** | **100.0%** | **1.02 [0.71, 1.49]** |
| Total events | 298 | | 564 | | | |

Heterogeneity: Tau$^2$=0.00; Chi$^2$=0.66, df=2 (P=0.72); I$^2$=0%
Test for overall effect: Z=0.13 (P=0.90)

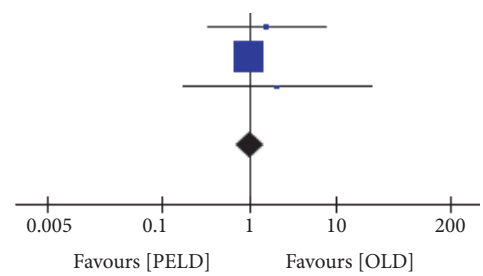



Figure 4: Forest plot of comparison: PELD versus OLD, outcome: 2 for MacNab classification (success rate).

| Study or Subgroup | PELD Mean | PELD SD | PELD Total | OLD Mean | OLD SD | OLD Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn (2016) | 9.63 | 2.31 | 32 | 10.68 | 2.67 | 34 | 40.9% | -1.05 [-2.25, 0.15] |
| Choi (2016) | 12.5 | 7.5 | 20 | 20.2 | 7.2 | 23 | 15.6% | -7.70 [-12.11, -3.29] |
| Lee (2009) | 20.7 | 15.9 | 25 | 18.2 | 15.4 | 29 | 5.7% | 2.50 [-5.88, 10.88] |
| Lee (2017) | 15.31 | 2.97 | 35 | 16.98 | 4.13 | 48 | 37.8% | -1.67 [-3.20, -0.14] |
| **Total (95% CI)** | | | **112** | | | **134** | **100.0%** | **-2.12 [-4.25, 0.01]** |

Heterogeneity: Tau$^2$=2.52; Chi$^2$=9.05, df=3 (P=0.03); I$^2$=67%
Test for overall effect: Z=1.95 (P=0.05)

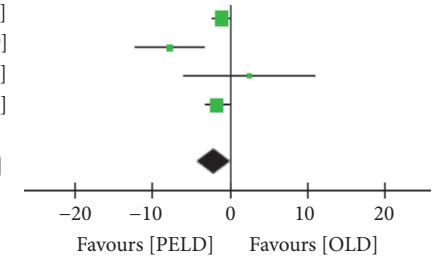



Figure 5: Forest plot of comparison: PELD versus OLD; outcome: 3 for ODI, final follow-up.

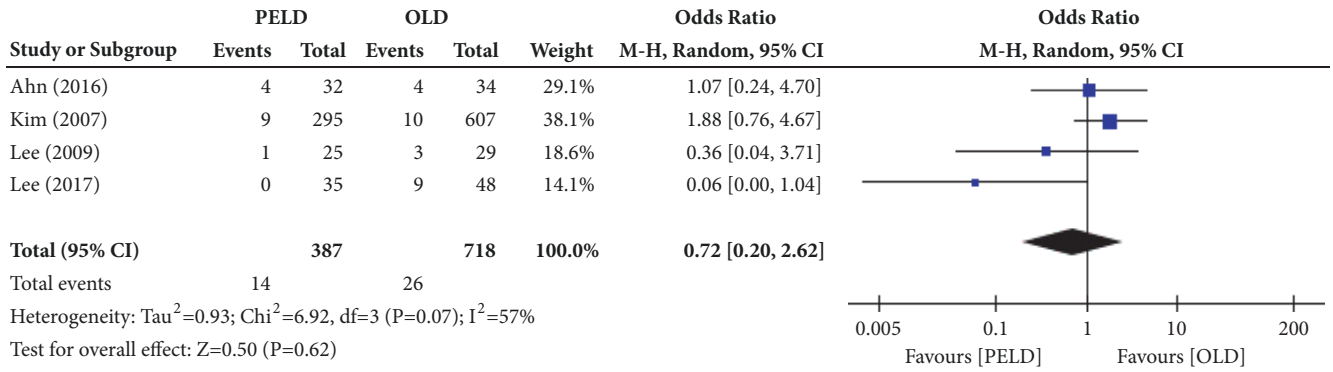



Figure 6: Forest plot of comparison: PELD versus OLD; outcome: 4 for complication rate.

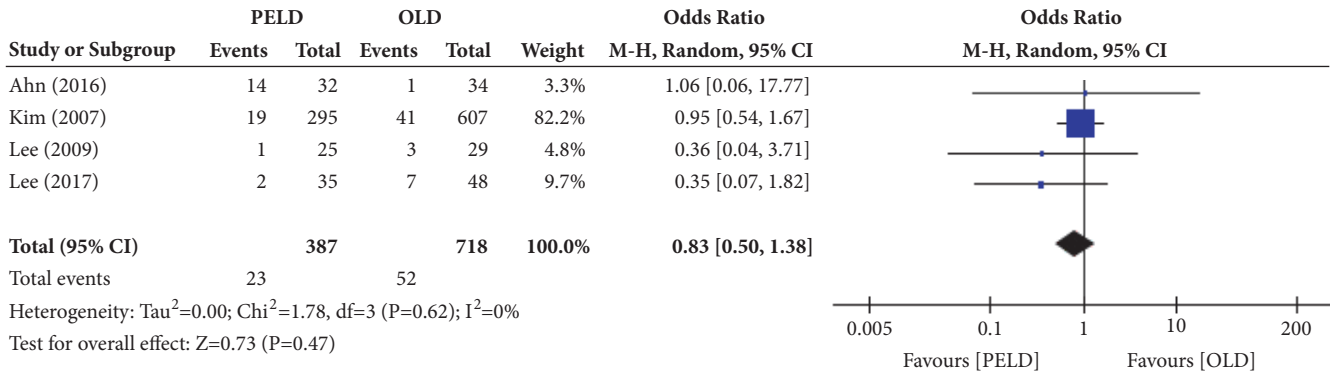



Figure 7: Forest plot of comparison: PELD versus OLD; outcome: 5 for recurrence rate.

p=0.62) (Figure 6). Heterogeneity existed between individual studies included in the analysis ($I^2$=57%, p=0.07).

*3.3.5. Recurrence Rate.* Among the 7 papers, 4 presented the results of the recurrence rate, and 1,105 subjects were included in the analysis: 387 in the PELD group and 718 in the OLD group. Twenty-three subjects in the PELD group and 52 in the OLD group had recurrence. There were no statistically significant differences in the recurrence rate between the PELD and OLD groups (OR=0.83; 95% CI=0.50, 1.38; p=0.47) (Figure 7). There was no heterogeneity between individual studies included in the analysis ($I^2$=0%, p=0.62).

*3.3.6. Reoperation Rate.* Among the 7 papers, 4 presented the results of the reoperation rate, and 1,065 subjects were included in the analysis: 372 in the PELD group and 693 in the OLD group. Thirty-one subjects in the PELD group and 43 subjects in the OLD group had reoperation. There were no significant differences in the reoperation rate between the PELD and OLD groups (OR=1.45; 95% CI=0.89, 2.35; p=0.13) (Figure 8). There was no heterogeneity between individual studies included in the analysis ($I^2$=0%, p=0.49).

*3.3.7. Operation Time.* Among the 7 papers, 6 presented the results of operation time, and 1,172 subjects were included in the analysis: 424 in the PELD group and 748 in the OLD group. The PELD group's average operation time was 55.84 min, and that of the OLD group was 83.99 min. The PELD group's average operation time was significantly shorter than that of the OLD group (MD=-23.06; 95% CI=-32.42, -13.70; p<0.00001) (Figure 9). Heterogeneity existed between individual studies included in the analysis ($I^2$=91%, p<0.00001).

*3.3.8. Hospital Stay.* Among the 7 papers, 5 presented the results of hospital stay, and 270 subjects were included in the analysis: 129 in the PELD group and 141 in the OLD group. The PELD group's average hospital stay was 2.69 days, and that of the OLD group was 7.47 days. The PELD group's average hospital stay was significantly shorter than that of the OLD group (MD=-4.64; 95% CI=-6.37, -2.90; p<0.00001) (Figure 10). Heterogeneity existed between individual studies included in the analysis ($I^2$=92%, p<0.00001).

## 4. Discussion

In general, OLD has been mostly performed as a surgical treatment for lumbar disc herniation. This technique could possibly lead to lumbar instability and iatrogenic injury as it requires the removal of some posterior structures such as lamina, ligament flavum, and facet joints, dissection of muscles near the spine, and pulling of nerve branches [22, 23]. In response, PELD, which had relatively smaller loss of posterior structures and faster early recovery, was introduced by Kambin and Gellman [24] and is recently used widely for its strength where it can be performed under local

| Study or Subgroup | PELD Events | PELD Total | OLD Events | OLD Total | Weight | Odds Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Ahn (2016) | 0 | 32 | 1 | 34 | 2.2% | 0.34 [0.01, 8.74] |
| Choi (2016) | 2 | 20 | 1 | 23 | 3.8% | 2.44 [0.20, 29.19] |
| Kim (2007) | 28 | 295 | 38 | 607 | 89.7% | 1.57 [0.94, 2.61] |
| Lee (2009) | 1 | 25 | 3 | 29 | 4.3% | 0.36 [0.04, 3.71] |
| **Total (95% CI)** | | **372** | | **693** | **100.0%** | **1.45 [0.89, 2.35]** |
| Total events | 31 | | 43 | | | |

Heterogeneity: $Tau^2$=0.00; $Chi^2$=2.40, df=3 (P=0.49); $I^2$=0%
Test for overall effect: Z=1.51 (P=0.13)

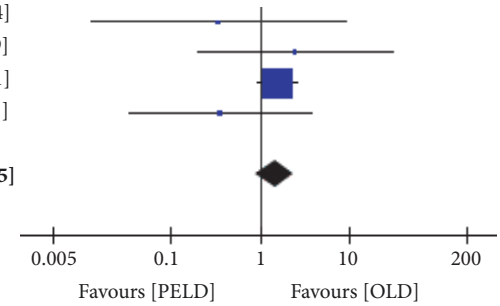



Figure 8: Forest plot of comparison: PELD versus OLD; outcome: 6 for reoperation rate.

| Study or Subgroup | PELD Mean | PELD SD | PELD Total | OLD Mean | OLD SD | OLD Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn (2016) | 48.66 | 6.45 | 32 | 53.71 | 8.49 | 34 | 21.5% | -5.05 [-8.67, -1.43] |
| Choi (2016) | 67 | 125 | 20 | 136.7 | 53 | 23 | 9.8% | -69.70 [-91.99, -47.41] |
| Jeong (2006) | 78 | 36.71 | 22 | 110 | 29.68 | 25 | 11.5% | -32.00 [-51.25, -12.75] |
| Kim (2007) | 53 | 13 | 295 | 64.6 | 28.7 | 607 | 21.8% | -11.60 [-14.32, -8.88] |
| Lee (2006) | 42.6 | 14.21 | 30 | 65.1 | 23.17 | 30 | 17.9% | -22.50 [-32.23, -12.77] |
| Lee (2009) | 45.8 | 11.1 | 25 | 73.8 | 25.7 | 29 | 17.5% | -28.00 [-38.32, -17.68] |
| **Total (95% CI)** | | | **424** | | | **748** | **100.0%** | **-23.06 [-32.42, -13.70]** |

Heterogeneity: $Tau^2$=102.63; $Chi^2$=57.44, df=5 (P=0.00001); $I^2$=91%
Test for overall effect: Z=4.83 (P=0.00001)

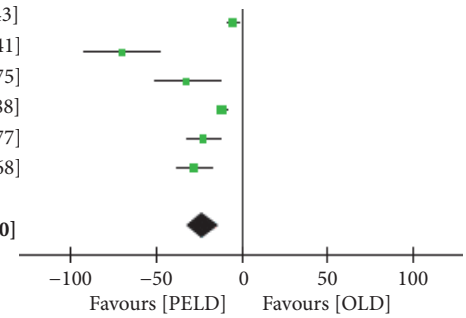



Figure 9: Forest plot of comparison: PELD versus OLD; outcome: 7 for operation (minute).

| Study or Subgroup | PELD Mean | PELD SD | PELD Total | OLD Mean | OLD SD | OLD Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Ahn (2016) | 7.5 | 2.63 | 32 | 15.65 | 4.8 | 34 | 18.0% | -8.15 [-10.00, -6.30] |
| Choi (2016) | 1.5 | 1.1 | 20 | 7.2 | 3.5 | 23 | 19.3% | -5.70 [-7.21, -4.19] |
| Jeong (2006) | 2.73 | 2.62 | 22 | 7.68 | 2.59 | 25 | 19.4% | -4.95 [-6.44, -3.46] |
| Lee (2006) | 0.81 | 1.26 | 30 | 3 | 2.5 | 30 | 21.1% | -2.19 [-3.19, -1.19] |
| Lee (2009) | 0.9 | 0.5 | 25 | 3.8 | 1.4 | 29 | 22.2% | -2.90 [-3.45, -2.35] |
| **Total (95% CI)** | | | **129** | | | **141** | **100.0%** | **-4.64 [-6.37, -2.90]** |

Heterogeneity: $Tau^2$=3.47; $Chi^2$=47.10, df=4 (P=0.00001); $I^2$=92%
Test for overall effect: Z=5.23 (P=0.00001)

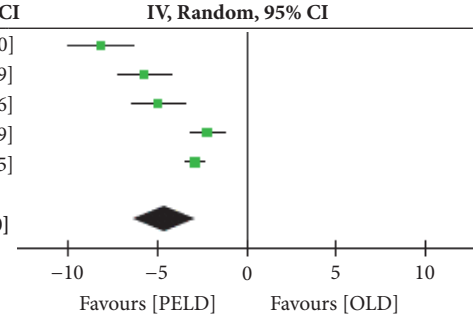



Figure 10: Forest plot of comparison: PELD versus OLD; outcome: 8 for hospital stay (days).

anesthesia [25]. However, PELD also has its downsides; that is, it insufficiently removes the disc, has a high recurrence rate, and requires a certain period of time to develop skill proficiency [26–28], and therefore it calls for a comparison of these two surgical methods for their stability and effect.

Recently, a meta-analysis, which compared OLD and PELD as surgical treatments for lumbar disc herniation, reported two cases in 2016 [29, 30]. Each meta-analysis was performed by extracting data from 7 papers; the papers were limited to those published after 2000, when endoscopic technology and tools were advanced, and as a result each one selected 5 and 6 papers. The studies conducted on Koreans patients accounted for a majority with 3 and 4 papers. Considering this could work as a bias, this study performed a meta-analysis only on those conducted on Korean patients.

In the present study, PELD showed statistically significantly better results than OLD in the VAS score (of both leg and back) at the final follow-up, ODI, operation time, and hospital stay. We believe it is especially meaningful that contrary to previous meta-analysis studies [29, 30] PELD showed better results in the VAS score as it is the primary outcome of the surgery. In previous meta-analysis studies [29, 30], PELD showed better results in operation time and hospital stay in both and this study, whereas PELD showed better results in the ODI in one of the two previous meta-analysis studies [29] and this study. PELD showed statistically

significantly better results in more items in this study than in previous studies. It is because endoscopic surgery has less damage to muscles and structures around the spine as well-known [31, 32]. In addition, we believe that the papers included in this study are relatively recent researches with the enough development of endoscopic instruments and proficiency of endoscopic skills.

The MacNab classification was recorded in only 3 among the 7 papers, and there were no significant differences between the two surgical methods. At the final follow-up, both surgical methods showed successful results. So, we have determined that both methods are effective.

In this study, there were no significant differences in reoperation and recurrence rate. There were two previous reports stating that there were no differences between the two surgical methods [14, 33] and there was another report that PELD had more recurrence and reoperation rate [26]. Usually, in such cases, there was a remaining disc piece or it was accompanied by stenosis due to reoperation and recurrence [34], and it would be important to determine appropriate indications as well as develop the proficiency of surgical skills.

Complications included infection, spinal cord injury, cerebrospinal fluid leak, damage to nerve roots, and postoperative sensory abnormalities [11, 16, 19, 20]. A previous report stated that PELD had fewer complications, thanks to the development of tools such as the camera system [35], but another reported that it would do more damage to the spinal cord and nerve roots due to a lack of depth [36]. In this study, each paper showed different results, and there were no statistically significant differences.

This study has some limitations. All 7 papers used for the meta-analysis were nonrandomized trials, and there was selection bias as a result. The quality of these trials was also fairly high. In addition, clinical heterogeneity existed in this study. Type of surgery (primary or revisional), surgical indications, treatment options before the operation, and follow-up period during the symptom period varied depending on the selected paper, and the sample size was small as well. Particularly revision surgery may demand different approach-related surgical technique and more operation time. They may be subject to more complications that do not exist during the initial surgery. Finally, a physician's proficiency makes a huge difference in PELD, and it is believed that the difference in physicians in each paper would have worked as a bias.

## 5. Conclusion

This meta-analysis found that PELD had significantly better results than OLD in the VAS score, ODI, operation time, and hospital stay as a surgical treatment for lumbar disc herniation in the Korean population. Nevertheless, OLD still showed good clinical results, and therefore a randomized controlled study with a large sample size would be required in the future to compare these two surgical methods.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## References

[1] P. J. Apostolides, R. Jacobowitz, and V. K. Sonntag, "Lumbar discectomy microdiscectomy: "the gold standard".," *Clinical Neurosurgery*, vol. 43, pp. 228–238, 1996.

[2] P. Campbell, G. Wynne-Jones, S. Muller, and K. M. Dunn, "The influence of employment social support for risk and prognosis in nonspecific back pain: a systematic review and critical synthesis," *International Archives of Occupational and Environmental Health*, vol. 86, no. 2, pp. 119–137, 2013.

[3] O. P. Gautschi, D. Cadosch, and G. Hildebrandt, "Acute low back pain—assessment and management," *Praxis*, vol. 97, no. 2, pp. 58–68, 2008.

[4] P. D. Angevine and P. C. McCormick, "Outcomes research and lumbar discectomy.," *Neurosurgical Focus*, vol. 13, no. 2, p. E8, 2002.

[5] R. A. Davis, "A long-term outcome analysis of 984 surgically treated herniated lumbar discs," *Journal of Neurosurgery*, vol. 80, no. 3, pp. 415–421, 1994.

[6] R. Casal-Moro, M. Castro-Menéndez, M. Hernández-Blanco, J. A. Bravo-Ricoy, and F. J. Jorge-Barreiro, "Long-term outcome after microendoscopic diskectomy for lumbar disk herniation: a prospective clinical study with a 5-year follow-up," *Neurosurgery*, vol. 68, no. 6, pp. 1568–1575, 2011.

[7] M. Wenger, L. Mariani, A. Kalbarczyk, and U. Gröger, "Long-term outcome of 104 patients after lumbar sequestrectomy according to Williams," *Neurosurgery*, vol. 49, no. 2, pp. 329–335, 2001.

[8] J. N. A. Gibson, J. G. Cowie, and M. Iprenburg, "Transforaminal endoscopic spinal surgery: the future 'gold standard' for discectomy?—a review," *The Surgeon*, vol. 10, no. 5, pp. 290–296, 2012.

[9] A. T. Yeung and P. M. Tsou, "Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases," *The Spine Journal*, vol. 27, no. 7, pp. 722–731, 2002.

[10] Y. Ahn, S.-H. Lee, W.-M. Park, H.-Y. Lee, S.-W. Shin, and H.-Y. Kang, "Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases," *The Spine Journal*, vol. 29, no. 16, pp. E326–332, 2004.

[11] D. Y. Lee, C. S. Shim, Y. Ahn, Y.-G. Choi, H. J. Kim, and S.-H. Lee, "Comparison of percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for recurrent disc herniation," *Journal of Korean Neurosurgical Society*, vol. 46, no. 6, pp. 515–521, 2009.

[12] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Recurrent lumbar disc herniation after conventional discectomy: a prospective, randomized study comparing full-endoscopic interlaminar and transforaminal versus microsurgical revision," *Journal of Spinal Disorders & Techniques*, vol. 22, no. 2, pp. 122–129, 2009.

[13] D. A. Ditsworth, "Endoscopic transforaminal lumbar discectomy and reconfiguration: A posterolateral approach into the spinal canal," *World Neurosurgery*, vol. 49, no. 6, pp. 588–598, 1998.

[14] J. L. Schaffer and P. Kambin, "Percutaneous posterolateral lumbar discectomy and decompression with a 6.9-millimeter cannula: analysis of operative failures and complications," *The Journal of Bone & Joint Surgery*, vol. 73, no. 6, pp. 822–831, 1991.

[15] A. Stang, "Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses," *European Journal of Epidemiology*, vol. 25, no. 9, pp. 603–605, 2010.

[16] S. S. Ahn, S. H. Kim, D. W. Kim, and B. H. Lee, "Comparison of outcomes of percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for young adults: a retrospective matched cohort study," *World Neurosurgery*, vol. 86, pp. 250–258, 2016.

[17] K.-C. Choi, J.-S. Kim, and C.-K. Park, "Percutaneous endoscopic lumbar discectomy as an alternative to open lumbar microdiscectomy for large lumbar disc herniation," *Pain Physician*, vol. 19, no. 2, pp. E291–E300, 2016.

[18] J. S. Jeong, S. H. Lee, S. J. Lee, and B. W. Hwang, "The Clinical Comparison between Open Surgery and Percutaneous Endoscopic Lumbar Discectomy in Extraforaminal Lumbar Disc Herniation," *Journal of Korean Neurosurgical Society*, vol. 39, no. 6, pp. 413–418, 2006.

[19] M.-J. Kim, S.-H. Lee, E.-S. Jung et al., "Targeted percutaneous transforaminal endoscopic diskectomy in 295 patients: comparison with results of microscopic diskectomy," *World Neurosurgery*, vol. 68, no. 6, pp. 623–631, 2007.

[20] J. Lee, H. Kim, Y. Pee, J. Jang, and I. Jang, "Comparison of Percutaneous Endoscopic Lumbar Diskectomy and Open Lumbar Microdiskectomy for Recurrent Lumbar Disk Herniation," *Journal of Neurological Surgery Part A: Central European Neurosurgery*, 2017.

[21] S.-H. Lee, S.-E. Chung, Y. Ahn, T.-H. Kim, J.-Y. Park, and S.-W. Shin, "Comparative radiologic evaluation of percutaneous endoscopic lumbar discectomy and open microdiscectomy: a matched cohort analysis," *Mount Sinai Journal of Medicine*, vol. 73, no. 5, pp. 795–801, 2006.

[22] I. Thongtrangan, H. Le, J. Park, and D. H. Kim, "Minimally invasive spinal surgery: a historical perspective.," *Neurosurgical Focus*, vol. 16, no. 1, p. E13, 2004.

[23] G. Xin, H. Shi-Sheng, and Z. Hai-Long, "Morphometric analysis of the YESS and TESSYS techniques of percutaneous transforaminal endoscopic lumbar discectomy," *Clinical Anatomy*, vol. 26, no. 6, pp. 728–734, 2013.

[24] G. P. Jasper, G. M. Francisco, and A. E. Telfeian, "Endoscopic transforaminal discectomy for an extruded lumbar disc herniation," *Pain Physician*, vol. 16, no. 1, pp. E31–E35, 2013.

[25] G. Choi, S.-H. Lee, P. P. Raiturker, S. Lee, and Y.-S. Chae, "Percutaneous endoscopic interlaminar discectomy for intracanalicular disc herniations at L5-S1 using a rigid working channel endoscope," *Neurosurgery*, vol. 58, no. 1, pp. ONS-59–ONS-68, 2006.

[26] J. Cheng, H. Wang, W. Zheng et al., "Reoperation after lumbar disc surgery in two hundred and seven patients," *International Orthopaedics*, vol. 37, no. 8, pp. 1511–1517, 2013.

[27] H. Wang, B. Huang, C. Li et al., "Learning curve for percutaneous endoscopic lumbar discectomy depending on the surgeon's training level of minimally invasive spine surgery," *Clinical Neurology and Neurosurgery*, vol. 115, no. 10, pp. 1987–1991, 2013.

[28] Y. Ahn, C.-H. Kim, J. H. Lee, S.-H. Lee, and J.-S. Kim, "Radiation exposure to the surgeon during percutaneous endoscopic lumbar discectomy: A prospective study," *The Spine Journal*, vol. 38, no. 7, pp. 617–625, 2013.

[29] X. Li, Y. Han, Z. Di et al., "Percutaneous endoscopic lumbar discectomy for lumbar disc herniation," *Journal of Clinical Neuroscience*, vol. 33, pp. 19–27, 2016.

[30] W. Ruan, F. Feng, Z. Liu, J. Xie, L. Cai, and A. Ping, "Comparison of percutaneous endoscopic lumbar discectomy versus open lumbar microdiscectomy for lumbar disc herniation: A meta-analysis," *International Journal of Surgery*, vol. 31, pp. 86–92, 2016.

[31] H. M. Mayer and M. Brock, "Percutaneous endoscopic lumbar discectomy (PELD)," *Neuro Surgical Review*, vol. 16, no. 2, pp. 115–120, 1993.

[32] S. Tenenbaum, H. Arzi, A. Herman et al., "Percutaneous Posterolateral Transforaminal Endoscopic Discectomy: Clinical Outcome, Complications, and Learning Curve Evaluation," *Surgical Technology International*, vol. 21, pp. 278–283, 2011.

[33] H. J. Goald, "Microlumbar discectomy: Follow-up of 477 patients," *Microsurgery*, vol. 2, no. 2, pp. 95–100, 1980.

[34] P. Kambin, "Arthroscopic microdiscectomy," *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, vol. 8, no. 3, pp. 287–295, 1992.

[35] S. Ruetten, M. Komp, H. Merk, and G. Godolias, "Surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach versus conventional microsurgical technique: A prospective, randomized, controlled study - Clinical article," *Journal of Neurosurgery: Spine*, vol. 10, no. 5, pp. 476–485, 2009.

[36] O. Righesso, A. Falavigna, and O. Avanzi, "Comparison of open discectomy with microendoscopic discectomy in lumbar disc herniations: results of a randomized controlled trial," *Neurosurgery*, vol. 61, no. 3, pp. 545–549, 2007.