Functional outcomes of full-endoscopic spine surgery for high-grade migrated lumbar disc herniation: a prospective registry-based cohort study with more than 5 years of follow-up

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Abstract

Background: Full-endoscopic lumbar discectomy (FELD) is an alternative to posterior open surgery to treat a high-grade migrated herniated disc. However, because of the complexity of the surgery, success is dependent on the surgeon’s skill. Therefore, patients are frequently treated using open discectomy. Anatomical constraints and technical difficulties can lead to the incomplete removal of high-grade migrated discs.

Methods: We retrospectively reviewed patients who had undergone FELD performed by a single surgeon between January 2010 and January 2014 from a prospective spine registry in an institute. Perioperative records and data of the Oswestry Disability Index, visual analog scale scores (preoperatively and 2 weeks, 6 weeks, 3 months, 6 months, 1 year, 2 years, and 5 years after the operation), and MacNab criteria were collected.

Results: Of 58 patients with a follow-up duration of > 5 years, (41 and 17 patients had undergone transforaminal endoscopic lumbar discectomy [TELD] and interlaminar endoscopic lumbar discectomy [IELD], respectively), the satisfaction rate was 87.8% (five unsatisfactory cases) for TELD and 100% for IELD. The overall percentage of patients with good to excellent results according to modified MacNab criteria was 91.3% (53/58 patients). Two patients had residual discs. Two patients needed an open discectomy due to recurrent disc herniation. One IELD patient received spinal fusion surgery due to segmental instability after 5 years.

Conclusion: FELD has a high success rate for the management of high-grade migrated herniated discs. In patients with high-grade disc migration from L1 to L5, TELD is effective and safe. However, for L4–L5 and L5–S1 high-grade upward and downward disc migration, IELD is the favorable option and provides high patient satisfaction.

Keywords: Discectomy, Full-endoscopic lumbar discectomy, Migrated disc herniation
Background
In 1975, Hijikata described the first percutaneous discectomy; since then, full-endoscopic lumbar discectomy (FELD) has been frequently used for managing lumbar disc herniation [1, 2]. This alternative to conventional open discectomy has many benefits, such as decreased tissue trauma; lower postoperative instability; no interference with the epidural venous system, which, if damaged, may result in fibrosis and chronic neural edema; and faster recovery [3, 4].

Although FELD has many advantages, the indication for its use is mostly observed in patients with nonmigrated or low-grade migrated disc herniation. The incidence of migrated discs is approximately 35–72%, and most patients have a downward low-grade migrated disc (30.9%) [5, 6]. However, high-grade migrated discs are commonly observed (an incidence of 34% for migrated discs) [6, 7]. Because of the high failure rate of FELD in high-grade migrated disc herniation, open surgery is usually suggested; moreover, FELD is usually difficult because of anatomical barriers encountered when removing high-grade migrated discs, which can result in the incomplete removal of the disc material [4, 8].

Recently, the development of instruments and techniques has enabled the use of FELD to correct high-grade migrated lumbar discs. Many spine surgeons have developed novel techniques for managing high-grade migrated disc herniation by using FELD, including expanding the entry point of the transforaminal endoscopic lumbar discectomy (TELD) approach by using the foraminoplastic technique [4, 9–11], the transfacet process and pedicle-complex approach [12], two-level TELD [8], contralateral TELD [13], the suprapedicular approach [14], and the transpedicular approach [15, 16]. Alternatively, surgeons may opt to use a technique involving the posterior route, including the translaminar approach [17, 18], the interlaminar endoscopic lumbar discectomy (IELD) approach [19, 20], or adjacent IELD [21], which are similar to open surgery. Although improvements in equipment and techniques have resulted in better outcomes in FELD than in conventional open surgery, the management of high-grade migrated discs remains a challenge. In this study, we examined the long-term outcomes of patients with high-grade migrated disc herniation treated using FELD, and we reviewed the literature for the analysis of relevant surgical techniques.

Methods
Patients and evaluation
We retrospectively reviewed patients who had received FELD by a single surgeon between January 2010 and January 2014 from a prospective spine registry in an institute. Data concerning patients’ age, sex, and treatment time as well as follow-up data were collected. The computed tomography (CT) and magnetic resonance imaging (MRI) scans of patients were used to determine the level and extent of pathology. An intraoperative fluoroscopy examination was performed to ensure the correct positioning of the endoscope. The successful removal of migrated discs was determined using intraoperative findings (dural pulsation, loose neural element, retrieved disc fragments, and intraoperative symptoms) and postoperative symptoms. Herniated discs were classified using the radiological classification of migrated disc herniations provided by Lee et al. [22] (Table 1, Fig. 1). Migration into zone 1 and zone 4 was considered high-grade migration.

Exclusion criteria
Patients were excluded if they had spinal stenosis confirmed through CT or MRI; exhibited segmental instability; exhibited other pathological conditions, such as acute inflammation, infection, fractures, or tumors; or were lost to follow-up within 5 years. This study was approved by our institutional review board (TMU-JIRB No.: N201903139).

Surgical technique
Surgical position
During surgery, each patient was placed in a prone position to allow hip flexion to increase the available working space. This position reduces lordosis, allowing easy access to the spine.

TELD
For high migration at the L1–L2 to L4–L5 level, the transforaminal epiduroscopic approach was selected (Figs. 2, 3, and 4). Patients were locally anesthetized using 1% lidocaine. Before starting the surgery, the

Table 1 Radiological Classification of Migrated Disc Herniation [22]

| Zone | Direction       | Range of Distance                                                                 |
|------|-----------------|-----------------------------------------------------------------------------------|
| Zone 1 | Far upward    | From the inferior margin of the upper pedicle to 3 mm below the inferior margin of the upper pedicle |
| Zone 2 | Near upward    | From 3 mm below the inferior margin of the upper pedicle to the inferior margin of the upper vertebral body |
| Zone 3 | Near downward  | From the superior margin of the lower vertebral body to the center of the lower pedicle |
| Zone 4 | Far downward   | From the center to the inferior margin of the lower pedicle |
Fig. 1 Radiological classification of migrated disc herniation

Fig. 2 L2–L3 transfemoral full-endoscopic lumbar discectomy (TELD) for L2–L3 high-grade upward migration disc at zone 1. a Preoperative magnetic resonance imaging (MRI) lateral view showing an L2–L3 high-grade upward-migrated disc. b Intraoperative endoscopic view showing the L3 traversing root and epidural space. c The use of a flexible probe tip to pull out the migrated disc near zone 1 of the L2 vertebra. d Removed blue-stained migrated disc fragment.
patient was placed in a prone position. To establish the entry site, preoperative imaging studies along with intraoperative fluoroscopy were conducted. The skin entry depended on the patient and was generally 8–15 cm lateral from the midline. The approach angle for the disc depended on the direction and zone of the disc location. If the disc exhibited upward migration, then a caudal to cranial approach angle was selected, whereas if the disc exhibited caudal migration, then a cranial to caudal approach was adopted. Methylene blue dye was injected into the disc space to visualize the leakage pattern in the annular fissure. Dilatation was subsequently performed, and endoscopic exploration was initiated. Intradiscal subannular debulking was performed until the border of

![Fig. 3 TELD for L4-L5 high-grade downward migrated herniated disc at zone 4. a Preoperative MRI lateral view showing an L4–L5 downward migrated disc. b Postoperative MRI lateral view showing complete decompression after the removal of the migrated disc. c and d Intraoperative fluoroscopy view showing flexible dissecting forceps probing down-migrated disc fragments at zone 4. e Removed disc fragments](image)

![Fig. 4 Contralateral TELD for upperward migration of L3-L4 HIVD at zone 1. a Anterior to posterior view of intraoperative fluoroscopy showing the endoscopic micro rongeur forceps grasping the disc fragment at contralateral zone 1. b Lateral view of the intraoperative fluoroscopy working channel position located at the epidural space](image)
the annular fissure was uncovered. The outer layer of the annulus and the posterior longitudinal ligament were cut using a pair of annulus scissors. Once the outer annulus and posterior longitudinal ligament were cut, the epidural layer was released after the confirmation of the epidural space and the fragment of the migrated disc. This ventral decompression was expected to create additional working space to approach the disc that had migrated in the cranial or caudal direction. The herniated disc was observed after completing the epidural and intradiscal release. A pair of flexible forceps was used to remove the tip of the migrated disc under endoscopic and fluoroscopic guidance. The disc could be removed in one piece or in multiple pieces. Next, complete herniotomy was conducted by removing the entire herniation along with the intradiscal fragment, periannular

Fig. 5 L4–L5 and L5–S1 interlaminar full-endoscopic lumbar discectomy (IELD) for L4–L5 high-grade downward migrated disc at zone 4 due to difficulty reaching the migrated fragment from L4–L5 IELD. a Preoperative MRI lateral view showing L4–L5 high-grade downward migration. b Preoperative MRI axial view showing L4–L5 herniated disc. c Postoperative MRI lateral view showing removal of the migrated disc. d Postoperative MRI axial view showing the removal of the migrated disc. e Intraoperative fluoroscopic view of the two working channels of the double IELD approach. f Intraoperative fluoroscopic view showing IELD from the L4–L5 interlaminar window for L4–S1 zone 4. g Intraoperative fluoroscopic view showing IELD for L5–S1 zone 1
fragment, and fragment that had migrated from the site. For two L3–L4 upward-migrated discs, contralateral TELD was used.

IELD

IELD was performed in patients with L4–L5 high-grade downward disc migration or L5–S1 disc migration (Figs. 5, 6, and 7). The surgery was performed under general anesthesia. Patients were placed in the prone position, with their hips flexed to increase the interlaminar space. Soft tissue expanders were used to separate muscles to facilitate the insertion of the cannula and endoscope. The inferior edge of the cranial lamina on the side of the lesion and the ligamentum flavum (LF) were exposed using the endoscopic camera. To gain access to the spinal canal, a small incision was created on the LF by using a laminectomy rongeur. For L4–L5 discectomy, a variable drill was used to resect the cranial lamina to enlarge the interlaminar space. For L5–S1 discectomy, the spinal canal was exposed after dissecting the LF. A drill was used in some cases with narrow interlaminar space, such as L5–S1, to create an area easier to work in. Finally, the exposed herniated nucleus pulposus was removed to decompress the nerve root. In one patient with an L5–S1 upward migration disc, an L4–L5 and L5–S1 biportal-IELD was chosen.

Statistical analysis

GraphPad Prism 5 (La Jolla, CA, USA) was used to assess data. Data are expressed as the mean and range. Multiple t tests were performed to assess functional outcomes. To compare baseline demographic data between IELD and TELD, the chi-square value was calculated. The t test was also used to analyze differences between continuous variables such as the length of stay and operation time. Significance was set at $P < 0.05$ for all the tests.

![Fig. 6](image-url) L4–L5 TELD changed to L5–S1 IELD for L4–L5 high-grade downward migration. a Preoperative MRI lateral view showing high-grade downward migrated disc herniation at the L4–L5 level. b Preoperative MRI axial views showing disc herniation at the L4–L5 level. c Intraoperative fluoroscopic view of the herniated disc material. d Fluoroscopy anteroposterior view showing forceps near the disc fragment during L4–L5 TELD. e Fluoroscopy lateral view showing the forceps grasping the disc fragment during L5–S1 IELD. f Removed disc fragments.
Results

Patient demographic and perioperative data
A total of 68 patients with single-level high-grade migrated discs were enrolled in this study, and 58 patients were followed up for > 5 years (Table 2). In total, 41 and 17 patients underwent TELD and IELD, respectively. One patient received biportal-IELD for L4–L5 high-grade downward migration (Fig. 5). The operated levels included L1–L2 (1 patient, 1.47%), L2–L3 (4 patients, 5.88%), L3–L4 (6 patients, 8.82%), L4–L5 (36 patients, 67.65%), and L5–S1 (11 patients16.18%; Table 2). The average follow-up duration was 6.1 years (range: 5.1–9.2 years). No difference in patient demographics or length of stay was observed between the IELD and TELD groups. However, the TELD group had more patients with zone 1 migration in proximal-level disc herniation ($P = 0.032$) and shorter operation time ($P = 0.045$) than did the IELD group.

Functional outcomes
Overall visual analog scale (VAS) scores for back pain showed a significant improvement from 6 weeks after the operation (Table 3, Fig. 8). Patients who underwent TELD exhibited faster improvement (3 months postoperatively) than did those who underwent IELD (1 year postoperatively); however, no significant difference was observed between the two patient groups. The overall and individual VAS scores for leg pain all significantly improved from 2 weeks after the operation. The Oswestry Disability Index (ODI) significantly improved from 6 weeks postoperatively in both the approaches after the operation.

The percentage of patients with good to excellent results according to the modified MacNab criteria was 91.3% (53/58 patients). Among the 41 patients who received TELD, the satisfaction rate was 87.8%; five patients exhibited unsatisfactory results. Two patients had a residual disc (1 patient had a repeat TELD the following day, and one patient changed from L4–L5 TELD to L5–S1 IELD during the surgery; Fig. 5). Two patients required an open discectomy due to recurrent disc herniation. One patient (who received IELD) had spinal fusion surgery due to segmental instability after 5 years. The good to excellent result rate was 100% in the 17 patients who underwent IELD.

Discussion
Long-term surgical outcomes in high-grade disc migration
After Kambin introduced the posterolateral percutaneous lumbar disc decompression technique in 1973, the use of minimally invasive surgery has become increasingly common [23]. The advancement of specialized tools, such as flexible probes, lasers, and endoscopes, has
made FELD highly popular [24]. FELD has been limited
to the management of low-grade migrated lumbar disc
herniation and has not been used for highly migrated
discs, which pose technical challenges to spine surgeons
[17]. Lee et al. reported that patients with high-grade
migration had a significantly higher incidence of failure
(21.1%) than did those with low-grade migration [22].
Recently, various techniques have been developed to
treat high-grade migrated discs, and these techniques
have shown promising results (Table 2). In our study,
we found that TELD and IELD both resulted in satisfac-
tory long-term functional outcomes for high-grade mi-
grated disc herniation.

**TELD for migrated discs**

TELD and open disectomy have exhibited similar re-
results in the management of soft high-grade disc migra-
tion; moreover, TELD is a safe and effective procedure
especially from L1 to L5 [11]. The migratory patterns of
the disc fragment are usually restricted by the attach-
ment of the posterior longitudinal ligament, peridural
membrane, and midline septum [25]. Thus, to enter the
foramen, they remain on the lateral side of the midline
[4]. Osman et al. showed that without sacrificing

| Table 2 Demographic and Clinical Characteristics of Patients |
|---------------------------------|
| Overall | TELD | IELD | P |
|________|_______|_______|__|
| Overall | 58 | 41 | 17 | 0.462 |
| Age (years) | 56.3 (18–78) | 56.7 (18–72) | 55.2 (18–78) | 0.332 |
| Sex | 38F 20M | 27F 14M | 11F 6M | 0.175 |
| ASA | 1 | 32 | 24 | 8 | 0.175 |
| 2 | 15 | 10 | 5 | 0.032 |
| 3 | 11 | 6 | 5 | 0.511 |
| Zone 1 | | | | |
| L1–L2 | 1 | 1 | 0 | 0 |
| L2–L3 | 4 | 4 | 0 | 0 |
| L3–L4 | 4 | 4 | 0 | 0 |
| L4–L5 | 10 | 8 | 2 | 0.045 |
| L5–S1 | 7 | 0 | 7 | 0.617 |
| Zone 4 | | | | |
| L1–L2 | 0 | 0 | 0 | 0 |
| L2–L3 | 0 | 0 | 0 | 0 |
| L3–L4 | 2 | 2 | 0 | 0 |
| L4–L5 | 26 | 21 | 5 | 0.072 |
| L5–S1 | 4 | 1 | 3 | 0.617 |
| Operation duration (minutes) | 55.7 (28–128) | 50.6 (28–85) | 65.5 (45–128) | 0.045 |
| Length of stay (days) | 5.2 (3–7) | 4.6 (3–6) | 5.8 (3–7) | 0.082 |
| Follow-up (years) | 6.1 (5.1–9.2) | 6.3 (5.1–7.8) | 5.7 (5.5–9.2) | 0.617 |

ASA American Society of Anesthesiologists classification, IELD Interlaminar endoscopic lumbar discectomy, TELD Transforaminal endoscopic lumbar discectomy

stability, transforaminal decompression can create a con-
siderably larger intervertebral foraminal space compared
with posterior decompression (45.5% vs. 34.2% increase)
[23]. Furthermore, upward-migrated herniations are
common in older patients with associated comorbidities
such as diabetes and hypertension, making them ineli-
gible to receive general anesthesia and open surgery [26,
27]. Positioning the patient to achieve hip flexion and
low lordosis enlarges the foramen; consequently, the
space is sufficiently large for performing TELD without
requiring foraminoplasty. However, for zone 1 and zone
4 migration, Kim et al. reported a transforaminal supra-
pedicular approach with a flexible semirigid curved
probe. Curved forceps are extremely useful for the
complete removal of very-high-grade disc migration,
allowing the surgeon to reach distant sites and remove
disc fragments without further bone resection and re-
lease soft tissue adhesions [4].

Reamers and endoscopic drills, endoscopic osteo-
tomes, and trepans can help remove the barrier of the
pedicle to the disc for highly migrated discs. When per-
foming this step, the surgeon should be extremely care-
ful to prevent neural damage or the significant removal
of bony structures leading to lumbar instability. Thus,
surgeons are recommended to use endoscopic drills or endoscopic osteotomes to increase precision.

In this study, patients who received TELD had higher VAS and ODI scores than did those who received IELD, probably because TELD caused less damage than IELD through the facet joint during the exploration of the migrated disc. Furthermore, TELD has a shorter operating time than IELD does because TELD requires less bone work and soft tissue management.

The zone with highest number of failed cases of TELD in the present study was in zone 1. The migrated disc at the ipsilateral side was usually blocked by the pedicle unless contralateral TELD was used [13]. The surgeon may be unable to grasp the fragment due to the nonflexible instrument being unable to make an acute turn to reach the area. The contralateral approach enables the surgeon to reach the fragment directly because the angle between the instrument and the migrated fragment is straight. If a bone drill or trephine is available, the use of the translaminar approach [17], transpedicular approach [15, 28], or keyhole procedure for directly targeting the migrated disc can result in a satisfactory outcome. Foraminoplasty is needed to access high-grade migrated disc herniations for multiple reasons. First, lumbar herniation occurs most frequently at lower levels. The diameter of the intervertebral foramen decreases in the lumbar area,

Table 3 Satisfaction in patients receiving interlaminar and translaminar endoscopic lumbar discectomy

|               | Overall (N=58) | IELD (N=17) | TELD (N=41) | P value |
|---------------|----------------|-------------|-------------|---------|
|               | Mean           | SD          | Mean        | SD      | Mean     | SD          |          |
| Preop VAS for back | 2.22           | 1.57        | 2.34        | 1.76    | 2.29     | 1.76        | 0.92     |
| Postop 2 weeks | 2.30           | 1.68        | 2.30        | 1.76    | 2.45     | 1.69        | 0.76     |
| Postop 6 weeks | 1.44           | 1.60        | 1.50        | 1.68    | 1.55     | 1.72        | 0.92     |
| Postop 3 months| 1.40           | 1.20        | 1.39        | 1.32    | 1.51     | 1.31        | 0.75     |
| Postop 6 months| 1.20           | 1.10        | 1.35        | 1.03    | 1.44     | 1.12        | 0.78     |
| Postop 1 year | 1.03           | 0.84        | 1.07        | 0.82    | 1.05     | 0.77        | 0.93     |
| Postop 2 years| 0.46           | 0.80        | 0.45        | 0.85    | 0.48     | 0.85        | 0.90     |
| Postop 5 years| 0.45           | 0.60        | 0.44        | 0.63    | 0.44     | 0.63        | > 0.99   |
| Preop VAS for leg | 6.21           | 1.64        | 2.34        | 1.70    | 2.29     | 1.66        | 0.92     |
| Postop 2 weeks | 2.33           | 1.85        | 2.30        | 1.82    | 2.45     | 1.87        | 0.76     |
| Postop 6 weeks | 1.52           | 1.30        | 1.50        | 1.31    | 1.55     | 1.31        | 0.92     |
| Postop 3 months| 1.38           | 0.72        | 1.39        | 0.73    | 1.51     | 0.73        | 0.75     |
| Postop 6 months| 0.72           | 0.87        | 1.35        | 0.90    | 1.44     | 0.82        | 0.78     |
| Postop 1 year | 0.64           | 0.72        | 1.07        | 0.73    | 1.05     | 0.73        | 0.93     |
| Postop 2 years| 0.57           | 0.73        | 0.45        | 0.74    | 0.48     | 0.71        | 0.90     |
| Postop 5 years| 0.43           | 0.50        | 0.44        | 0.50    | 0.44     | 0.50        | > 0.99   |
| Preop ODI     | 46.73          | 13.07       | 46.24       | 13.20   | 46.67    | 13.36       | 0.91     |
| Postop 2 weeks| 45.00          | 12.12       | 45.18       | 12.25   | 45.76    | 11.83       | 0.87     |
| Postop 6 weeks| 33.51          | 14.71       | 33.06       | 14.88   | 33.73    | 14.90       | 0.88     |
| Postop 3 months| 19.63          | 10.38       | 18.76       | 9.81    | 19.46    | 10.27       | 0.81     |
| Postop 6 months| 20.40          | 12.57       | 20.77       | 12.84   | 20.66    | 12.90       | 0.98     |
| Postop 1 year | 11.18          | 10.14       | 10.84       | 10.38   | 11.11    | 10.41       | 0.93     |
| Postop 2 years| 8.72           | 4.41        | 8.83        | 4.44    | 8.86     | 4.41        | 0.98     |
| Postop 5 years| 6.60           | 3.53        | 6.30        | 3.42    | 6.46     | 3.49        | 0.87     |

Modified MacNab

|            | Overall (N=58) | IELD (N=17) | TELD (N=41) |
|------------|----------------|-------------|-------------|
| Excellent  | 36             | 11          | 25          |
| Good       | 17             | 6           | 11          |
| Fair       | 4              | 0           | 4           |
| Poor       | 1              | 0           | 1           |

IELD Interlaminar endoscopic lumbar discectomy, ODI Oswestry disability index, TELD Transforaminal endoscopic lumbar discectomy, VAS visual analog scale
from cranial to caudal. Narrowing may result from degenerative changes due to the hypertrophy and the overriding of facets and the thickening of the LF. For adequate decompression, the anterior epidural space must be reached under direct visual control. Enlarging the foramen by undercutting the superior articular facet can facilitate reaching the epidural space and ensure the adequate exposure or complete removal of the fragment [29].

IELD

In this study, IELD was more effective than TELD for L4–L5 high-grade downward and L5–S1 high-grade upward and downward migration discs, except in failed cases. Axillary herniated discs can be easily removed using IELD. The S1 nerve root exit at the L5–S1 level disc space is unique. The angle between the S1 root and thecal sac allows access to the axillary portion of the S1 nerve root. An increase in the angle between the root and thecal sac in axillary disc herniation increases the working space for the cannula without damaging the root. IELD can directly access the axillary herniated disc and remove the disc fragment with minimal manipulation of the neural structure. However, with the use of TELD, incomplete decompression or a remnant disc is possible. The posterior longitudinal ligament must be cut to retrieve the dorsally migrated disc fragment [19].

As shown in Table 4, after gaining the in-depth knowledge of surgical anatomy and ensuring strict adherence to technical guidelines, endoscopic surgery does not yield poor outcomes when performed for managing high-grade disc migration. Using an accurate approach for the proper indication remains the most crucial point. Doctors must gain in-depth knowledge of surgical anatomy and ensure strict adherence to technical guidelines; familiarity with IELD and TELD is particularly important. TELD is preferred for shoulder-type disc herniation, centrally located disc herniation, and recurrent disc herniation. IELD is preferred for axillary-type disc herniation and migrated discs, particularly high-grade disc migration and disc herniation.

A limitation of this study is the retrospective nature of data collection. However, the prospective spine registry effectively collected postoperative function scores, which reduced missing data. In addition, selection bias due to
| Name           | Surgical Technique                  | Details                                                                                                                                                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|---------------|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------|-----------|------------|------------|------------|----------------------|
| Gun Choi 2008 | PELD with foraminoplasty under     | Anesthetizing methods/positioning: Local anesthesia with the patient in prone position Site of annular puncture: L4–L5 and below: Medial pedicular line L3–L4 and above: Midpedicular line Inclination of the Needle Trajectory: Approximately 30° with the lower or upper endplate Down-migrated herniation: Remove undersurface of the articular process Use endoscopic drill with a round diamond burr tip to removal bony part Allows for placement for endoscope in anterior epidural space Ligamentum flavum, fibrotic bands, part of anulus removed using Holmium: Yttrium–Aluminum–Garnet (YAG) laser Intermittently blocking the irrigation fluid outflow allows traversing nerve root to move freely: Confirms complete decompression Up-migrated herniation: Use of round-ended cannula Placement of cannula at the lower part of the disc Upward shifting with twisting motion till the exiting root is partially visible Release of the foraminal ligament and the Ligamentum flavum using laser Removal of the exposed ruptured fragment with forceps | 59       | 91.4% of patients experienced satisfactory outcome Good: 37 patients (63.8%) Fair: 16 (27.6%) Poor: 4 patients (69%) Poor: 1 (1.7%) | 8.01      | 1.56        | 61.6       | 10.76      | 2                     |
| Hyeun Sung Kim 2009 | Endoscopic transforaminal         | Anesthetizing methods: Favor local anesthetic Skin entry approximately 8–12 cm from the midline Removal of the superior margin of the pedicle Spondylosis in the upper margin of the lower vertebrae Traversing nerve root is exposed Remove ruptured disc material Inferior migrated ruptured material below the traversing nerve root Be aware of not to injure the traversing nerve root Semirigid flexible curved forceps to pull the disc material Bleeding may occur. Use bipolar | 53       | N/a             | Leg: 9.32 ± 0.43 | Leg: 1.78 ± 0.71 | 79.82 ± 4.53 | 1527 ± 3.82 | N/a                   |
| Name                  | Surgical Technique                                                                 | Details                                                                                                                                                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|----------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------|-----------|------------|------------|------------|---------------------|
| G. Choi 2010 [19]    | Percutaneous Endoscopic Lumbar Herniectomy for high-grade down-migrated L4-L5 disc through an L5-S1 IELD | Anesthetizing methods/positioning: • Lateral decubitus position with the affected side upwards • Conscious sedation Skin entry point: Used 1% lidocaine to 0.5-mm to 0.7-mm skin incision Herniectomy was performed using various grasping forceps and side-firing holmium-YAG laser Flexible tip of the Elman radiofrequency probe can be used for hemostasis and tissue dissection. | 4        | N/a             | Back: 3.75 | Leg: 8.3   | Back: 1.75 | Leg: 0.75 | 65% 3% N/a          |
| Kyeong-seong Yeom 2011 [13] | Full endoscopic contralateral transforaminal discectomy | Anesthetizing methods/positioning: • Prone position on a radiolucent operating table • Epidural anesthesia Skin entry site: L3-L4 and L4-L5 levels Dorsal portion of the facet joint of index level on the lateral view of the C-arm. Inject a mixture of indigo-carmine and radio-opaque dye Endoscope was inserted to the anterolateral side of facet joint Foraminoplasty was done provided enough working space Using C-arm guidance to confirm facet articulation Insert trephine removed anterolateral bony portions of the facet joint • Unsuccessful: Micro-osteotome under endoscopic visualization was used for foraminoplasty Explore site between the posterior longitudinal ligament and the dural sac. - Protect the dural sac by turning the working sheath ventrally facing the posterior longitudinal ligament | 12       | Excellent: 10 Good: 2 | Back: 6.8 | Radicular pain: 8.2 | Back: 1.5 | N/a         | N/a N/a N/a         |
| Jianwei Du 2016 [17]  | Translaminar approach                                                              | Anesthetizing methods/positioning: • Prone position with mild flexion of the hips and knees • Local anesthesia Target site of puncture: 8 to 10 mm from midline Building of the working cannula | 7        | N/a             | 7.6 ± 0.8 | 1.3 ± 0.8 | 61.6       | 84         | 0                   |
| Name          | Surgical Technique                        | Details                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Hemiation |
|---------------|-------------------------------------------|-------------------------------------------------------------------------|----------|-----------------|-----------|------------|-----------|------------|---------------------|
| Yong Ahn 2004 | Standardized technique of transforaminal PELD | Anesthetizing methods/positioning                                      | 13       | Excellent: 4 patients (30.8%) | 7.86 ± 1.28 | 2.54 ± 1.51 | 1 year: 1.85 ± 1.07 | 84.92 ± 6.36 | 6 weeks: 2783 N/a ± 7.34 | 1 year: 17.54 ± 13.40 |
| Jinwei Ying 2016 | Transforaminal PELD | Anesthetizing methods/positioning                                      | 73       | Excellent: 14 patients | 7.5 ± 1.65 | 2.6 ± 1.75 | 1 year: 2.3 ± 1.5 | 85.1 ± 6.48 | 6 weeks: 2783 N/a ± 7.34 | 1 year: 17.54 ± 13.40 |
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Table 4 Literature review of full endoscopic spine surgery to manage high-grade migrated lumbar disc herniation (Continued)

| Name           | Surgical Technique | Details                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|----------------|--------------------|-------------------------------------------------------------------------|----------|-----------------|-----------|------------|------------|------------|---------------------|
| MacNab         |                    |                                                                         |          |                 |           |            |            |            |                     |
|                | Interlaminar PELD  | Entry point 10–13 cm from the midline                                  |          |                 |           |            |            |            |                     |
|                |                    | Mixture of methylene blue and iohexol (2 mL)                           |          |                 |           |            |            |            |                     |
|                |                    | Partial pediculectomy was done if fragment of disc was blocked by the pedicle or more space was needed for manipulation |          |                 |           |            |            |            |                     |
|                | Interlaminar PELD  | 18-gauge spinal needle was inserted into the disc with the conventional PELD |          |                 |           |            |            |            |                     |
|                |                    | 2 mL mixture of methylene blue and iohexol for discography             |          |                 |           |            |            |            |                     |
|                |                    | Partial medial laminectomy can be performed if view is blocked        |          |                 |           |            |            |            |                     |
|                | Contralateral Transforaminal PELD | Entry point approximately 14 cm from the midline |          |                 |           |            |            |            |                     |
|                |                    | An 18-gauge spinal needle was introduced into the disc under fluoroscopic guidance |          |                 |           |            |            |            |                     |
|                |                    | A mixture of methylene blue and iohexol (2 mL) for discography         |          |                 |           |            |            |            |                     |
|                |                    | Dyed migrated disc fragment was observed                               |          |                 |           |            |            |            |                     |
|                |                    | MRI was performed 24 h after surgery confirm complete decompression    |          |                 |           |            |            |            |                     |
| Chi Heon Kim   | TELD               | Anesthetizing methods/positioning                                       | 18       |                 |           |            |            |            |                     |
| 2016 [20]      | Percutaneous endoscopic interlaminar discectomy                       | Prone position                                                         |          |                 |           |            |            |            |                     |
|                |                    | General anesthesia                                                      |          |                 |           |            |            |            |                     |
|                |                    | Superior migration                                                      |          |                 |           |            |            |            |                     |
|                |                    | Interlaminar window at the same level of the disc herniation           |          |                 |           |            |            |            |                     |
|                |                    | Inferior migration                                                      |          |                 |           |            |            |            |                     |
|                |                    | Interlaminar window at a lower level than the disc                     |          |                 |           |            |            |            |                     |
|                |                    | Entry point                                                             |          |                 |           |            |            |            |                     |
|                |                    | Sagittal CT scan at midway between the medial margin of the lamina and the spinous process |          |                 |           |            |            |            |                     |
|                |                    | Extension line was drawn to the skin                                    |          |                 |           |            |            |            |                     |
|                |                    | Point of intersection between the extension line and skin was the entry point |          |                 |           |            |            |            |                     |
|                |                    | Enlargement of laminar window                                           |          |                 |           |            |            |            |                     |
|                |                    | Superior migration: not needed                                           |          |                 |           |            |            |            |                     |
|                |                    | Inferior migration: needed                                               |          |                 |           |            |            |            |                     |
|                |                    | Discography                                                             |          |                 |           |            |            |            |                     |
|                |                    | Posterolateral approach using indigo carmine mixed with radio-opaque dye |          |                 |           |            |            |            |                     |
|                |                    | Ligamentum flavum was opened or split                                   |          |                 |           |            |            |            |                     |
|                |                    | Compromised more than 50% of the anterior–posterior diameter of the spinal |          |                 |           |            |            |            |                     |

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| Name                  | Surgical Technique                  | Details                                                                                                                                                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|-----------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------|-----------|------------|-----------|------------|----------------------|
| Guntram Krzok         | Transpedicular Lumbar Endoscopic Surgery | - Ligamentum flavum: Open, less than 50% split Identify thecal sac and root Remove disc material                                                                                                             | 21       | N/a             | 8.1       | 1.3        | N/a       | N/a        | N/a                  |
| Xinbo Wu              | TELD Two-channel technique          | - Anesthetizing methods/positioning: Prone Local anesthesia with lidocaine (1%) Surgical puncture point: 10 cm from the midline for L3-L4 segment 11–14 cm from midline for L4-L5 segment Lateral fluoroscopy confirmed the needle positioned above the vertebral foramen Remove the blue-stained disc sequestration with bendable forceps | 22       | Excellent: 14, Good: 6, Fair: 2 | Back: 7.82 ± 0.96, Leg: 8.59 ± 1.05 | Back: 1.14 ± 0.71, Leg: 0.95 ± 0.72 | 71.18 ± 7.90, 1691 ± 4.13 | 1                     |
| Kyung-Chul Choi       | Epiduroscopic Laser Neural Decompression (ELND) for Down-migrated Disc Herniation | - Anesthetizing methods/positioning: Prone Local anesthesia | 1       | N/a             | N/a       | N/a        | N/a       | N/a        | N/a                  |
| Name                        | Surgical Technique                      | Details                                                                                                                                                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|-----------------------------|----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------|-----------|------------|------------|------------|----------------------|
| 2016 [5, 9]                 | Underwent PELD via the transforaminal route for removal of a paracentral extruded disc  |
|                             | Opening of the epidural space between the extruded disc and traversing nerve root  |
|                             | Cannula location  |
|                             | 25° trajectory angle  |
|                             | Between the spinous process and medial pedicle line on anteroposterior radiography  |
|                             | Herniated disc was removed using endoscopic forceps  |
|                             | Using bipolar and endoscopic scissor, release the outer annulus and posterior longitudinal ligament  |
|                             | ELND was done via sacral hiatus for removal of the down-migrated disc by using a Holmium: YAG laser  |
|                             | The flexible epidural fiber optic catheter system was inserted through the sacral hiatus  |
|                             | With fluoroscopic guidance, catheter went up to the pedicle along the ventral surface of the epidural space  |
|                             | Differentiate nerve root under epiduroscopic view and vaporized with laser (5 J at 5–10 Hz)  |
|                             | Performing PELD remove free fragments with forceps  |
| Hyeun Sung Kim 2018 [14]    | Percutaneous endoscopic transforaminal lumbar discectomy  |
|                             | Percutaneous endoscopic interlaminar lumbar discectomy  |
|                             | Anesthetizing methods/positioning  |
|                             | Prone position  |
|                             | Spine needle insertion point  |
|                             | Toward the lowest part and most dorsal part of disc space  |
|                             | Infiltrated with 7–10 mL 1% lidocaine followed by epinephrine mixed 2–3 cc 1.6% lidocaine, 3–5 min after the first injection  |
|                             | Discography using a contrast mixture consisting of 6 mL iohexol dye and 1 mL indigo-carmine  |
|                             | Tapered cannulated obturator inserted over the guide wire and advanced into the foraminal space  |
|                             | Internal disc decompression  |
|                             | Remove tissue around the pedicle  |
|                             | Perform suprapedicular circumferential opening technique  |
|                             | Drilling ventral part of superior articular process, the upper part of pedicle that builds the suprapedicular notch, upper- | 98 | Poor: 1 (1.0%)  |
|                             | Leg: 7.13  |
|                             | Fair: 3 (2.9%)  |
|                             | Good: 54 (51.9%)  |
|                             | Excellent: 46 (44.2%)  |
| Name                  | Surgical Technique                  | Details                                                                 | Patients | Modified MacNab | VAS Preop | VAS Postop | ODI Preop | ODI Postop | Recurrent Herniation |
|----------------------|-------------------------------------|-------------------------------------------------------------------------|----------|-----------------|-----------|------------|-----------|------------|----------------------|
| Quillo-Olvera 2018   | PELD transpedicular approach        | Anesthetizing methods/positioning                                       | N/a      | N/a             | N/a       | N/a        | N/a       | N/a        | N/a                  |
|                      |                                     | • Prone with hips and knees in flexion                                  |          |                 |           |            |           |            |                      |
|                      |                                     | • Local anesthesia with conscious sedation                              |          |                 |           |            |           |            |                      |
|                      |                                     | • 10 cm lateral from the midline for the L3 pedicle                    |          |                 |           |            |           |            |                      |
|                      |                                     | • 11 cm lateral from the midline for the L4 pedicle                    |          |                 |           |            |           |            |                      |
|                      |                                     | • 12 cm lateral from the midline for the L5 pedicle                    |          |                 |           |            |           |            |                      |
|                      |                                     | Skin is infiltrated with 1% lidocaine                                   |          |                 |           |            |           |            |                      |
|                      |                                     | An 18-gauge spinal needle is advanced and placed on the lateral wall of|          |                 |           |            |           |            |                      |
|                      |                                     | the pedicle, behind the transverse process                             |          |                 |           |            |           |            |                      |
|                      |                                     | The spinal needle is replaced with K wire                              |          |                 |           |            |           |            |                      |
|                      |                                     | Insert obturator and the tip should be placed on the lateral wall of   |          |                 |           |            |           |            |                      |
|                      |                                     | the pedicle                                                             |          |                 |           |            |           |            |                      |
|                      |                                     | Right pedicle at 3 o’clock, and for the left pedicle at 9 o’clock      |          |                 |           |            |           |            |                      |
|                      |                                     | 25° rod-lens endoscope of 6.3-mm outer diameter is advanced to visualize|          |                 |           |            |           |            |                      |
|                      |                                     | the lateral wall of the pedicle                                        |          |                 |           |            |           |            |                      |
|                      |                                     | Create a transpedicular tunnel                                          |          |                 |           |            |           |            |                      |
|                      |                                     | Remove a thin layer of cortical bone from its medial wall with         |          |                 |           |            |           |            |                      |
|                      |                                     | endoscopic Kerrison punch                                              |          |                 |           |            |           |            |                      |
|                      |                                     | • Endoscope is advanced through the tunnel to visualize the migrated   |          |                 |           |            |           |            |                      |
|                      |                                     | disc herniation directly                                                |          |                 |           |            |           |            |                      |
|                      |                                     | Endoscopic nerve hook used to confirm that the herniated disc has      |          |                 |           |            |           |            |                      |
|                      |                                     | been completely removed                                                |          |                 |           |            |           |            |                      |

*IELD Interlaminar endoscopic lumbar discectomy, ODI Oswestry disability index, PELD Percutaneous endoscopic lumbar discectomy, TELD Transforaminal endoscopic lumbar discectomy, VAS visual analog scale*
loss to follow-up remains a concern in this study. However, we had a follow-up rate of > 80% for patients with high-grade migrated discs, which reduced the bias. Furthermore, this study is limited by its small sample size, and the power of the study in comparing TELD and IELD was not evaluated. Additional studies comparing TELD and IELD for high-grade disc migration are needed. Another limitation of this study is long patient hospitalization due to affordable health care expenses, which may not be comparable to other studies.

Conclusion
FELD has a high success rate for the management of high-grade disc migration and disc herniation. TELD is effective and safe for patients with high-grade disc migration from L1 to L5. In patients with L4–L5 and L5–S1 high-grade upward and downward disc migration, IELD is a favorable option providing high patient satisfaction.

Abbreviations
FELD: Full-endoscopic lumbar discectomy; TELD: Transforaminal endoscopic lumbar discectomy; CT: Computed tomography; MRI: Magnetic resonance imaging; LF: Ligamentum flavum; VAS: Visual analog scale; ODI: Oswestry Disability Index

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Authors’ contributions
MHW and SKH were responsible for designing and setting up the study. C.W and MHW prepared the manuscript draft. All authors contributed to initial discussions regarding data extraction and analyses, the interpretation of study findings, and the development of the manuscript. All authors have critically reviewed and approved the final version of the submitted manuscript.

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Availability of data and materials
The data supporting our findings can be found in the article.

Ethics approval and consent to participate
This study was approved by Taipei Medical University- Joint Institution Review Board (TMU-JIRB No.: N201903139). The registry data, chart, and image reviews were approved with the waiver of informed consent.

Consent for publication
Not applicable.

Competing interests
The authors report no conflict of interest concerning the materials or methods used in this study or the findings stated in this manuscript.

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