Retrospective Study

Computed Tomography-Guided Endoscopic Surgery in Lumbar Disc Herniation With High-grade Migration: A Retrospective, Comparative Study

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Background: Symptomatic herniated intervertebral discs are debilitating. However, surgical management poses a significant challenge for endoscopic spine surgeons, especially in high-grade migrated lesions.

Objectives: This study aimed to assess the surgical and clinical outcomes after applying a computed tomography navigated percutaneous endoscopic lumbar discectomy.

Study Design: The data of patients with high-grade lumbar disc migration who underwent percutaneous endoscopic lumbar discectomy at our spine center were retrospectively collected and analyzed from November 2017 to May 2019. The patients were divided into 2 groups based on different workflows, with group O who underwent percutaneous endoscopic lumbar discectomy with computed-tomography navigation (O-arm), and group C who underwent conventional fluoroscopic guidance (C-arm).

Setting: Twenty-one (n = 21) patients were enrolled with data fully documented. There were 9 patients in group O (n = 9) and 12 patients in group C (n = 12).

Methods: An intraoperative 3-dimensional image was obtained using the O-arm device (O-arm®, Medtronic, Inc., Louisville, CO, United States) after patient positioning in group O, and enable multiplanar visualization during exploring the entry point, trajectory, orientation, and finally discectomy. In group C, conventional imaging scanner intensifier (C-arm) was used during the procedure.

Results: The operative time (99.4 ± 40.7 vs 86.9 ± 47.9 minutes, P = .129), blood loss (11.1 ± 15.7 vs 6.7 ± 8.2 mL, P = .602), and hospital stay (2.9 ± 0.3 vs 2.8 ± 0.6 days, P = .552) were similar between the 2 groups. However, group O showed more reduction in the pain and faster functional recovery immediately after the surgery (Visual Analog Score [VAS]: -9 vs -6.7, P =.277; Oswestry Disability Index [ODI]: -53.2% vs -29.1%, P = 0.006) and during the one-year follow-up (VAS: -8.1 vs -7.3, P =.604; ODI: -56.7% vs -40.1%, P = .053) compared with group C.

Limitations: The retrospective nature of the study design, the small population size, and the shorter period of follow-up required further study.

Conclusions: Computed tomography-navigated percutaneous endoscopic surgery is safe and effective for lumbar disc herniation with high-grade migration, and enhance early functional recovery even compared with conventional fluoroscopic guidance.

Key words: O-arm, C-arm, percutaneous endoscopic lumbar discectomy, lumbar disc herniation, high-grade migrated disc

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Lumbar disc herniation (LDH) is a troublesome disease that can cause pain and neurologic deficits (1), consequently affecting patients' work performance and quality of life (2). Moreover, it is highly prevalent among people of working age (3), and the direct costs from health care or indirect costs from lost wages and reduced productivity are enormous (4). For those who do not respond to the conservative management, surgical intervention is required for pain relief and resumption to a normal life.

The initial surgical goal for the treatment of LDH was to simply remove the pathologic disc compressing the dura and the nerve root, and later, many surgical techniques have been developed to minimize soft tissue and bone damage to enhance postoperative recovery and avoid destabilization. Since the introduction of the percutaneous endoscopic lumbar discectomy (PELD) through the posterolateral approach by Kambin et al (5) in 1983, PELD has become a popular technique for treating most kind of migration of LDHs (6) (10) due to its less invasive nature, rapid recovery, and shorter hospital stays with a wider spectrum of surgical indications. With the continuous advancement of surgical instruments and imaging systems, both short- and long-term outcomes have been more favorable. However, in dealing with high-grade migration of discs, extensive bone resection is required and damage to surrounding soft tissues is inevitable, which might result in less favorable clinical outcomes.

A real-time, high-resolution surgical imaging system appeared to address the difficulties associated with the challenging surgeries. The O-arm surgical imaging system was launched in the market in 2006, and was first delicately detailed, including a demonstration of the setting protocol in 2008 (7). Preliminary clinical application of the system was later described in 2011 (8) for cervical, upper thoracic, and thoracolumbar spine procedures. Its safety and efficacy were proven in general endoscopic lumbar spine surgery (9). However, limited findings have been reported on the treatment of LDH with high-grade migration by PELD assisted with the O-arm imaging system. In the present study, we aimed to analyze the feasibility, efficacy, and safety of the O-arm-assisted PELD in challenging cases with high-grade migrated discs.

Methods

This was a retrospective cohort study conducted at a single spine center in a tertiary referral hospital. We reviewed all patients diagnosed with symptomatic LDH with high-grade cranial or caudal migration and underwent PELD assisted by O-arm navigation (group O) or conventional fluoroscopic guidance (group C). The allocation of the workflow was primarily based on preoperative radiographic screening and magnetic resonance imaging (MRI). If more extensive bone resection was anticipated, the O-arm was introduced as the treatment modality. All surgeries were performed and supervised mainly by an experienced high-volume surgeon (HT Chen) who has performed more than 1,000 spinal surgeries using the O-arm. The Visual Analog Scale (VAS) score, Oswestry Disability Index (ODI) score, surgical parameters, and all the adverse effects related to the management were recorded before (baseline), immediately after the surgery (first assessment), and during the one-year follow-up (second assessment). The study was approved by the Research Ethics Committee of China Medical University and Hospital (CMUH109-REC1-119).

Patients

All adult patients with zone 1 (migrates upward across the level of 3 millimeters below the inferior margin of the superior pedicle) and zone 4 (migrates downward across the center of the inferior pedicle) herniation (10) (far-upward and far-downward) who underwent PELD with either O-arm navigation or fluoroscopic guidance were enrolled (Fig. 1). The detailed inclusion criteria were patients presenting with typical symptomatic LDH and neurologic signs, including sensory changes, motor weakness, or the presence of abnormal reflex, that corresponded with the preoperative images, including radiographic screening and MRI. In addition, the patients should have failed the conservative management for at least 3 months before surgery. The exclusion criteria were preoperative concomitant spondylolisthesis or deformity warranting correction or fusion, previous lumbar spine surgery, preoperative spinal infection, spinal tumor, or uncontrolled systemic diseases.

PELD With Fluoroscopic Guidance

The process started with endotracheal intubation, and the patient was placed and maintained on a radiolucent Jackson table (Modular Table System, Mizuho OSI, CA, United States) in the prone position. Surgical site preparation was performed in a sterile manner. After sterilization and draping, the trajectory was planned and conducted under fluoroscopic guidance (OEC EliteTM, GE Healthcare, UT, United States) with either an interlaminar or transforaminal approach

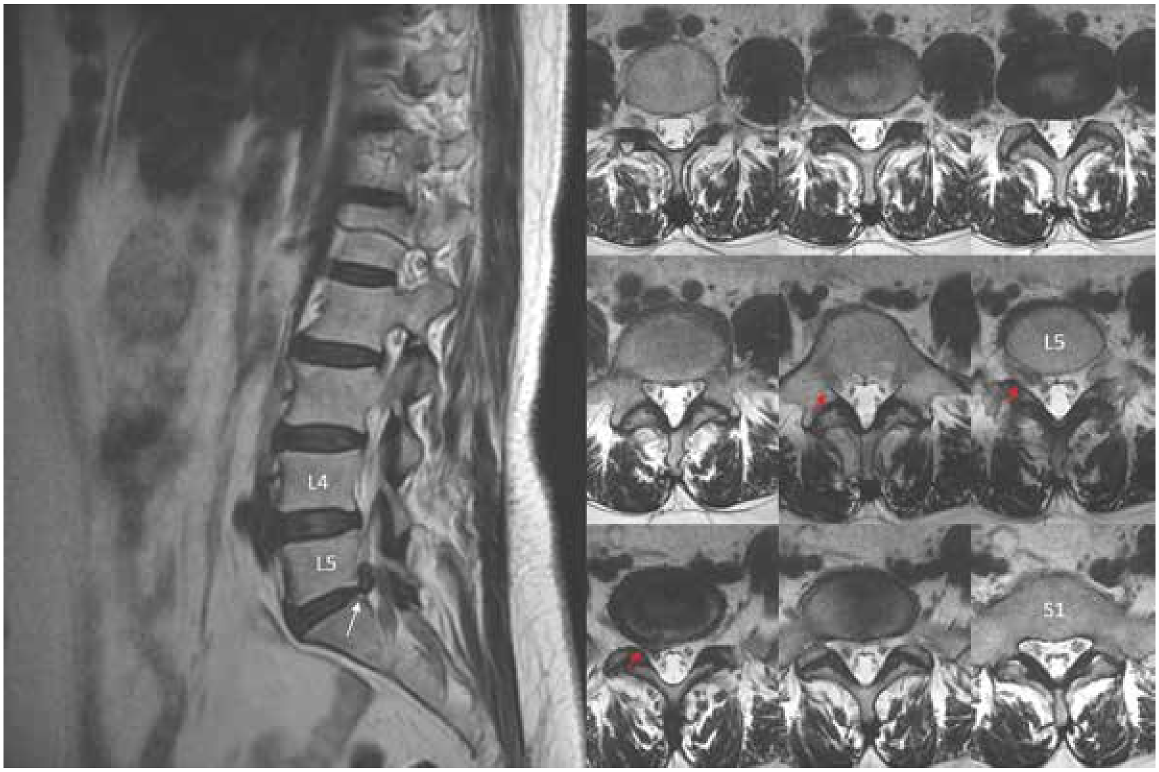

Fig. 1. *The T2-weighted MRI demonstrates high-grade upper migration of the intervertebral disc of the fifth lumbar and the first sacral spines reaching the upper pedicle level. The white arrow indicates the migrated disc in the sagittal view, while the red arrows indicates the vertical disc migration in the axial view.*

based on the preoperative fluoroscopic scan and MRI. In the transforaminal approach, the spinal needle was inserted at the junction between the endplate side of Kambin et al's (5) triangle and the pedicle with the assistance of anteroposterior and lateral fluoroscopy. A blunt dilator was introduced, and a working cannula was then passed over with the bevel rotated in the desired direction to block and protect the nerve root. Meanwhile, the interlaminar approach had an either slightly caudal to target the lower surface of the upper lamina or a slightly cranial trajectory to target the upper surface of the lower lamina based on the direction of the migrated lesion. Once there was concern with positioning or bone resection, the C-arm was utilized to confirm the current localization.

The operation time was defined as the duration from making a skin incision (around 8 mm) for the trajectory to wound dressing.

PELD With O-arm Navigation

The preparation was similar to that used for fluoroscopic guidance. After disinfection, the reference frame was inserted and fixed to the contralateral iliac crest of the targeted herniated disc. An intraoperative 3-dimensional image was obtained using the O-arm device (O-arm®, Medtronic, Inc., Louisville, CO, United States) after patient positioning, and transferred to a stereotactic navigation system (StealthStationTM, Medtronic, Inc., Louisville, CO, United States) to enable 3-dimensional visualization. Then, the registration of surgical instruments was done. With the aid of a virtual extension line and multiplanar images (Fig. 2), the trajectory was planned and performed based on combined planning with the preoperative MRI.

The trajectory was started using a pedicle access kit needle to penetrate the lumbar fascia into the interlaminar or transforaminal space with the preferred route. After confirming the route, the position could be set up and saved with the O-arm system for the following orientation, and the needle was replaced with a guidewire. A blunt dilator was introduced through the guidewire and advanced until the tip had contacted

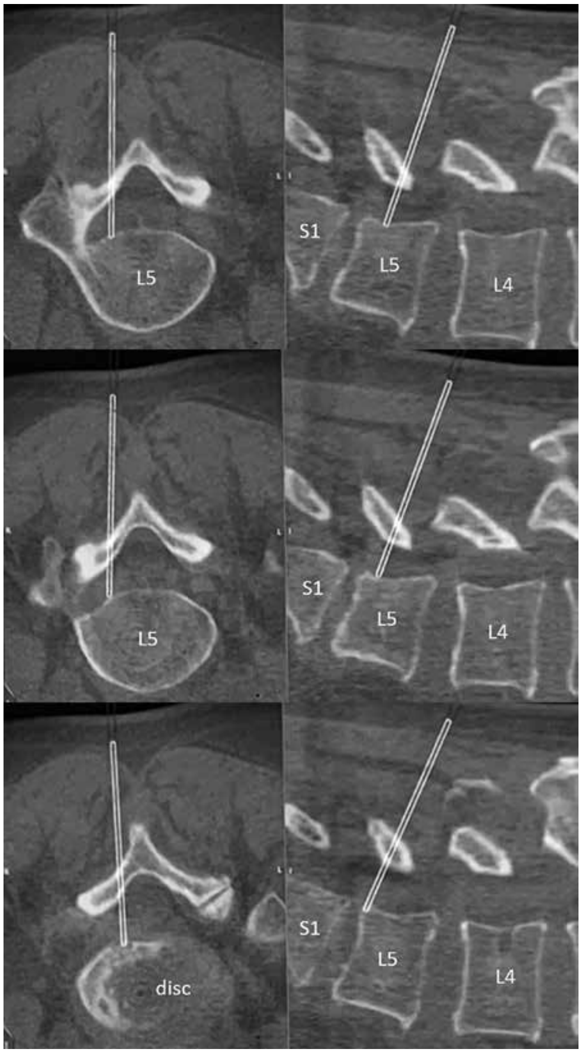

Fig. 2. *The multiplanar images from the coronal and axial views in the navigation system can aid in surgical planning. In this case, the "cross-segment technique" (through the interlaminar approach from the L4/5 to the L5/S1 lesion) was adopted to remove the extruded disc under O-arm navigation to minimize destruction and attain enough working space through the optimal route.*

the bone. A working cannula was then passed over, the dilator was removed, and an endoscope (Karl Storz Endoskope, Tuttlingen, Germany) attached to the universal tracker (SureTrak® II, Medtronic Inc., Minneapolis, MN, United States) was introduced.

Under O-arm guidance, partial laminotomy or partial facetectomy was performed, and soft tissues, such as the ligamentum flavum, were removed to reach the planned level for decompression. With O-arm navigation (usually with sagittal and axial views) and endoscopic monitoring, the approach with the least bony and unnecessary surrounding soft tissues destruction was foreseeable and performed to achieve adequate migrated disc removal and spinal decompression, while minimizing iatrogenic damage and the possibility of spinal instability. After discectomy, the working cannula and the reference frame were withdrawn, and the 2 incisions (usually around 8 mm) were closed.

The operation time was defined as the duration from making a skin incision for the reference frame and taking scanning images to wound dressing.

Visual Analog Scale

All patients were asked to measure the intensity of physical pain induced by LDH in the last 24 hours on a scale of 0 to 10 (11), with 0 indicating no pain at all and 10 indicating the worst possible pain.

Oswestry Disability Index

All the patients were asked to complete the questionnaire (12), which is composed of 10 aspects, including pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Each section required the patients to select the most applicable score, with 0 being the best condition and 5 being the worst condition. After adding the 10 scores to obtain the final score (range from 0 to 50), it was then divided by 50 to determine the total percentage (0%-100%), where a higher percentage index indicates a more severe functional impairment in daily activities.

Statistics

The baseline demographics were compared between the 2 study groups using Fisher's exact test. The treatment effects were analyzed using Mann-Whitney U test. The improvement rate was defined as the change over the period divided by the baseline. All tests were 2-tailed, and $P < 0.05$ was considered statistically significant. Data analyses were conducted using SPSS Version 22 (IBM Corporation, Armonk, NY, United States).

Results

From November 2017 to May 2019, 21 patients were enrolled in the study, with 9 patients in group O and 12 patients in group C (Table 1). The mean follow-up period was 50 weeks (48 weeks to 72 weeks). The gender percentage (women: 33% vs 17%, P = .255), mean age (53.4 ± 11.9 vs 45.3 ± 11.5 years old, P = .148),

Table 1. *Basic data of the patients.*

Case No.	Age and Gender	BMI	Level	Migration Zone	Approach	Follow-up Duration
A	39 M	22.3	L5/S1	4	IL	48 weeks
B	67 F	22.3	L2/3	4	TF	48 weeks
C	66 M	23.9	L3/4	1	TF	48 weeks
D	65 F	39.0	L4/5	4	TF	48 weeks
E	39 M	27.5	L4/5	1	IL	48 weeks
F	50 M	32.0	L3/4	4	IL	48 weeks
G	49 M	25.7	L5/S1	1	IL	72 weeks
H	63 F	23.3	L4/5	1	TF	48 weeks
I	43 M	23.9	L4/5	1	IL	48 weeks
a	35 F	23.0	L5/S1	4	IL	48 weeks
b	55 M	21.0	L5/S1	4	IL	72 weeks
c	33 M	26.3	L4/5	4	TF	48 weeks
d	44 M	32.3	L5/S1	1	IL	48 weeks
e	36 M	31.4	L4/5	4	IL	48 weeks
f	56 M	27.5	L4/5	4	TF	48 weeks
g	37 F	21.4	L5/S1	1	IL	48 weeks
h	58 M	29.8	L4/5	4	IL	48 weeks
i	69 M	22.5	L2/3	4	IL	48 weeks
j	42 M	25.5	L3/4	1	TF	48 weeks
k	41 M	23.5	L4/5	4	IL	48 weeks
l	40 M	29.4	L5/S1	4	IL	48 weeks

A to I indicates the patients in group O (n = 9); a to l indicates the patients in group C (n = 12).
Zone 1 indicates the disc migrates upward across the level of 3 millimeters below the inferior margin of the superior pedicle. Zone 4 indicates the disc migrates downward across the center of the inferior pedicle.
*M, male; F, female; BMI, body mass index; IL, interlaminar; TF, transforaminal.

mean body mass index (26.7 ± 5.6 vs 26.1 ± 3.9 kg/m^2, *P* = .972), back pain score (9.8 ± 0.4 vs 9.3 ± 1.6, *P* = .808), leg pain score (9.8 ± 0.4 vs 9.7 ± 0.9, *P* =.917), ODI score (73.6 ± 13.2% vs 63.7 ± 16.1%, *P* = .203), and migration zone percentage (upper: 56% vs 25%, *P* = .317) at baseline revealed no statistically significant differences between both groups (Table 2). Further, there were no statistically significant differences in the surgical parameters, including operative time (99.4 ± 40.7 vs 86.9 ± 47.9 minutes, *P* =.129), blood loss (11.1 ± 15.7 vs 6.7 ± 8.2 mL, *P* = .602), approach technique (IL: 56% vs 75%, *P* = .397) and length of hospital stay (2.9 ± 0.3 vs 2.8 ± 0.6 days, *P* = .552) between the groups (Table 3).

The back pain and leg pain improved more in group O, especially immediately after the operation (back: -9 vs -6.7; leg: -8.5 vs -7.3), although both groups demonstrated significant improvements after the surgery and during the follow-up (Tables 4 and 5, Figs. 3 and 4). Furthermore, in O-arm workflow, the results demonstrated

Table 2. *Summary baseline characteristics of patients.*

	Group O	Group C	*P* value
Total	9	12	
Demographics			
Female, n (%)	3 (33%)	2 (17%)	0.255
Age (years)	53.4 ± 11.9	45.3 ± 11.5	0.148
BMI	26.7 ± 5.6	26.1 ± 3.9	0.972
VAS Score			
Backache	9.8 ± 0.4	9.3 ± 1.6	0.808
Leg Pain	9.8 ± 0.4	9.7 ± 0.9	0.917
ODI score (%)	73.6 ± 13.2	63.7 ± 16.1	0.203
HGUM, n (%)	5 (56%)	3 (25%)	0.317
HGLM, n (%)	4 (44%)	9 (75%)	0.317

Data are presented as mean ± standard deviation.
*BMI, body mass index; VAS, visual analog scale; ODI, Oswestry disability index; HGUM, high-grade upper migration; HGLM, high-grade lower migration.

Table 3. *Comparisons of surgical parameters and results between 2 workflows.*

	Group O	Group C	*P* value
Operative Time (mins)	99.4 ± 40.7	86.9 ± 47.9	0.129
Estimated Blood Loss (mL)	11.1 ± 15.7	6.7 ± 8.2	0.602
IL Approach, n (%)	5 (56%)	9 (75%)	0.397
TF Approach, n (%)	4 (44%)	3 (25%)	0.401
Length of Hospital Stay (days)	2.9 ± 0.3	2.8 ± 0.6	0.552

Data are presented as mean ± standard deviation.
*IL, interlaminar; TF, transforaminal.

Table 4. *Postoperative pain and disability index during follow-ups.*

	Baseline	1st Follow-up	2nd Follow-up
Group O			
Backache	reference	0.8 ± 1.6‡	1.7 ± 1.8‡
Leg Pain	reference	1.3 ± 2.0‡	0.3 ± 0.5‡
ODI Score (%)	reference	20.4 ± 18.1‡	16.9 ± 11.3‡
Group C			
Backache	reference	2.6 ± 2.7‡	2.0 ± 2.8‡
Leg Pain	reference	2.4 ± 2.6‡	1.7 ± 2.5‡
ODI Score (%)	reference	34.6 ± 14.9†	23.6 ± 19.0‡

Data are presented as mean ± standard deviation.
† indicates *P*-value < 0.001.
‡ indicates *P*-value < 0.0001.

Table 5. *Improvement rates of the pain degree and QoL.*

	Baseline	1st Follow-up	2nd Follow-up
Group O			
Back Pain	-	92%	83%
Leg Pain	-	87%	97%
ODI Score	-	68%	77%
Group C			
Back Pain	-	72%	78%
Leg Pain	-	75%	82%
ODI Score	-	46%	63%

*QoL indicates quality of life.

significantly more functional recovery (ODI: -53.2% vs -29.1%, *P* = 0.006) compared with group C immediately after the surgery (Fig. 5). There was a difference of 20% (92% vs 72%) and 5% (83% vs 78%) in the improvement rates for back pain between groups O and C immediately after the surgery and during the follow-up, respectively. Also, there was a difference of 12% (87% vs 75%) and 15% (97% vs 82%) in leg pain reduction. At the second assessment, the patients in group O had almost fully recovered from radiculopathy (VAS: 0.3 ± 0.5). However, one patient in group C complained of recurrent back and leg pain, affecting the patient's activities of daily living. The patient was treated conservatively and was lost to follow-up.

Discussion

In our results, these 2 groups revealed marked reductions in pain immediately after the surgery and during the follow-up. Though, in the patients treated with the assistance of the O-arm, significant more improvement was demonstrated immediately after the surgery compared with the assistance with conventional fluoroscopic guidance. It might be due to the adequate decompression along with the minimization of soft tissue damage and bony destruction. Real-time, high-resolution multiplanar postpositioning images can aid in surgical planning and offer guidance for appropriate personalized trajectories, which may contribute to the different and more accessible entry points and routes of trajectory than by fluoroscopic guidance. During the procedure, a dilator and an endoscope loaded with the universal tracker were utilized to confirm the optimal route. Whether through the interlaminar, transforaminal approach, and even the "cross-segment approach" (from different bony level to reach the level of herniated disc), the workflow facilitated the optimal reference route in tracking and forecasting the possible bone removal. The decreased damage and controllable manipulation during the establishment of access for discectomy probably contributed to the delicate short- and long-term amelioration.

The rationale of minimally invasive surgery is to reduce any unnecessary iatrogenic injuries, and thus enhance patient outcomes. PELD has been demonstrated to cause less damage to soft tissues than open lumbar discectomy and markedly lower inflammatory responses after surgery (13). In our spine center, PELD has been the standard procedure as the surgical management to treat LDHs. Compared with an open lumbar microdiscectomy, PELD also showed rapid recovery and disc height preservation (14). In dealing with high-grade migrated disc herniation, different approaches and techniques have been developed for endoscopic surgery to overcome the limited working space. The transforaminal suprapedicular approach with a semirigid flexible curved probe has been used to remove far-downward migrated LDH in a case series and revealed satisfactory results (15). Another retrospective study (16) demonstrated PELD with foraminoplasty could address the herniations hidden by the anatomic barriers with a high success rate. The interlaminar approach has also been described for herniectomy through the adjacent interlaminar space (17), similar to the aforementioned "cross-segment" technique. Nevertheless, operative failure was foreseeable due to the difficult trajectory and poor visualization.

To achieve adequate exposure and decompression of the herniated disc during endoscopic surgery, the surgeon has to widen the working channel by undercutting more bony parts and ligaments or retracting the root and dura more forcefully, which could prolong the surgical time, increase the postoperative discomfort and risk for the patients, and may cause spinal instability and subsequent relapse. Tailor-made procedures (10,16,18) were required to remove the migrated disc, in each case, which made the surgery more challenging. In addition, the steep learning curve (19) and radiation exposure (20) are other issues to be addressed. With the advent of 3-dimensional real-time surgical imaging systems, surgical planning and outcomes for patients have further changed. One retrospective study (21) described that PELD combined with O-arm for establishing working trajectory showed good or excellent outcomes based on MacNab's criteria in 85.9% of patients. Based on our experience, the O-arm-navigated PELD could further aid in orientation when accessing and manipulating the targeted area with the universal tracker loaded in the endoscope. In a prospective cohort study (9), PELD assisted by O-arm navigation demonstrated a significant reduction in the operation time, cannula placement duration, and the difficulty of surgery. In our study, the mean operation time was longer in the O-arm group, which

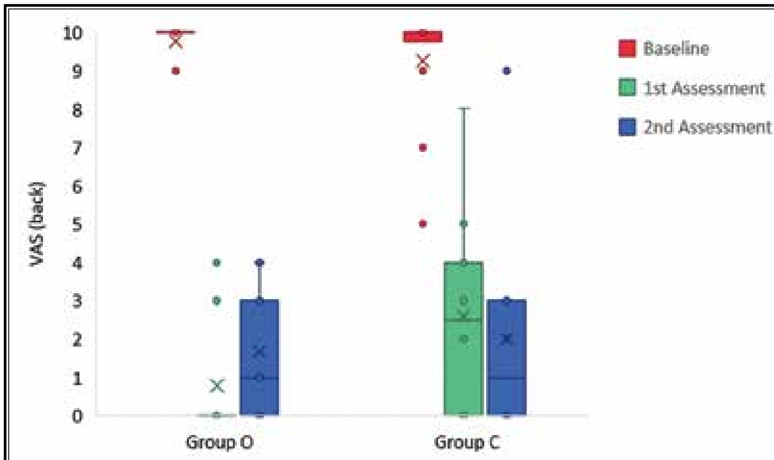

Fig. 3. *The box plot denotes the distribution of back pain in groups O and C during the follow-ups.*

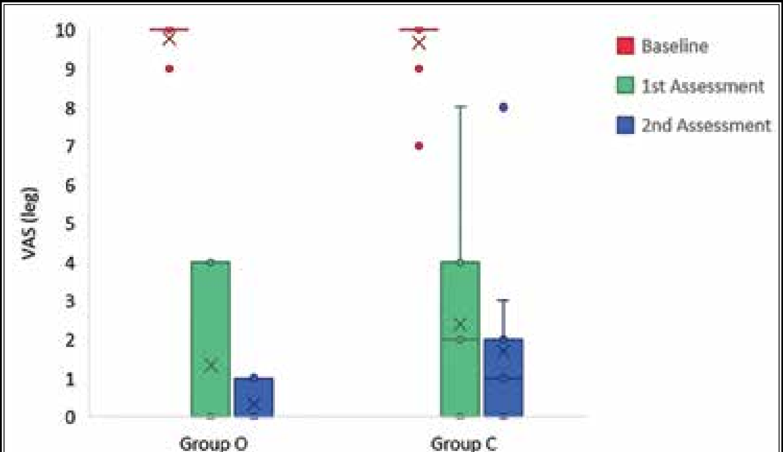

Fig. 4. *The box plot denotes the distribution of leg pain in groups O and C during the follow-ups.*

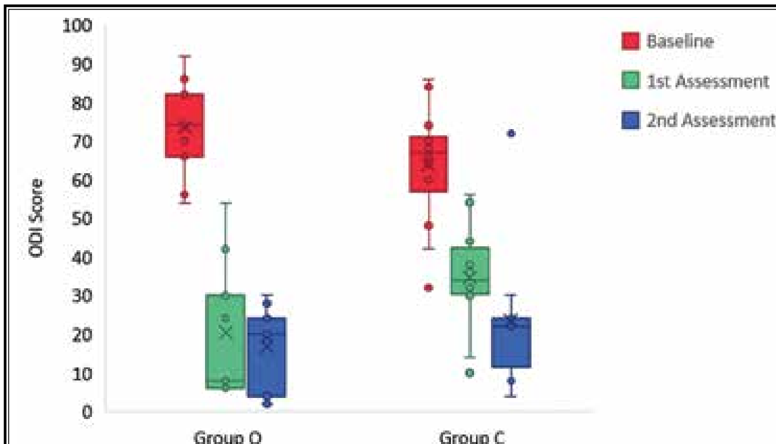

Fig. 5. *The box plot denotes the distribution of the ODI scores in groups O and C during the follow-ups.*

can be attributed to the setup of O-arm, the image scanning, and partly preoperative patient selection. Besides, more blood loss was observed in group O, which can be attributed to the wound made by the reference frame anchoring in the bone.

In addition, spinal endoscopic surgery combined with the O-arm has been applied in the treatment of spinal stenosis with lumbar spine deformity (22). Furthermore, radiation exposure for surgical teams can be completely avoided (20, 23). In our opinion, more clinical applications and solid data should be collected and analyzed to broaden the indications and avoid potential harm to patients.

Limitations

There were certain limitations to this study. The population size was small, and the follow-up duration was short. In addition, the study had inherent limitations due to its retrospective nature. However, the cases enrolled were rather severe and posed great challenges for endoscopic spine surgeons. This study demonstrated a delicate difference in the clinical outcomes of 2 minimally invasive workflows. Although our study showed favorable results for the O-arm workflow, the technique for retrieval of highly migrated herniation was still difficult and required skills and experiences.

Conclusions

PELD with O-arm navigation could provide a safe and efficacious treatment for patients with severe vertical LDH by reducing microtrauma and achieving adequate decompression through direct vision and multiplanar imaging assistance, and enhance early functional recovery even compared with conventional fluoroscopic guidance.

Acknowledgments

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