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Research article

Transforaminal endoscopic lumbar discectomy with targeted puncture and foraminotomy for very highly migrated disc herniation: A technique note with case series

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ABSTRACT

Background: Transforaminal endoscopic lumbar discectomy (TELD) has been widely used for lumbar disc herniation. However, in some challenging cases such as very highly migrated disc herniation (VHMDH), traditional TELD is difficult to access the pathology.

Methods: From January 2016 to December 2019, 63 patients with single-level VHMDH underwent TELD using targeted puncture and foraminotomy techniques were included. All patients were followed up for 26.5 months on average (range, 24–48 months). Operative time, length of hospital stay, visual analog scale (VAS) score, Oswestry Disability Index (ODI), modified MacNab criteria and surgical complications were evaluated.

Results: The operative time was 40–120 min (56.8 on average). The length of hospitalization was 2.5 days (range, 2–4 d). VAS score decreased significantly from 5.5 ± 1.3 preoperatively to 1.9 ± 1.30 ($p < 0.001$) 1 day postoperatively, and to 0.9 ± 0.8 ($p < 0.001$) at the final follow-up. ODI score improved significantly from 23.5 ± 3.2 preoperatively to 13.4 ± 3.0 ($p < 0.001$) 1 day postoperatively; and 3.1 ± 1.2 ($p < 0.001$) at the final follow-up. According to the modified MacNab criteria, 40 patients (63.5%) showed excellent results, 20 patients (31.7%) were rated as good, 2 patients (3.2%) were rated as fine, and 1 patient (1.6%) was rated as bad at the final follow-up. No residual fragments, nerve root or cauda equina injury was shown in this series. One recurrent case was resolved by open surgery.

Conclusions: With modified targeted puncture and foraminotomy techniques, VHMDH can be accessed safely and effectively, and satisfactory clinical outcomes can be obtained for these patients.

1. Introduction

Since it was introduced and applied in the 1970s, full-endoscopic lumbar discectomy has been extensively developed [1]. In line with different surgical entry approaches, full-endoscopic lumbar discectomy can be categorized according to two routes: transforaminal endoscopic lumbar discectomy (TELD) and interlaminar endoscopic lumbar discectomy (IELD) [2]. Both techniques are superior to conventional open surgery in light of their minimally invasive, painless and effective properties [3]. Currently, TELD, of which previously used nomenclature was percutaneous transforaminal endoscopic discectomy (PTED), is gaining increasing popularity among clinicians and patients.

Although the indications for TELD have expanded over time, there are still some challenges in treating very highly migrated disc herniation (VHMDH). VHMDH refers to cases in which the extent of migration is beyond the inferior margin level of either the upper pedicle or lower pedicle and is confirmed by preoperative magnetic resonance imaging (MRI) findings in the sagittal and coronal planes according to previous literature [4, 5] (Figure 1).

Normally, complete resection of very highly migrated disc fragments is difficult because of inadequate exposure to the TELD technique [6]; moreover, TELD is usually incapable of directly reaching and grasping the distal end of fragments from the traditional transforaminal approach [7]. Some researchers have pointed out that the key to successful endoscopic surgery lies in the accurate approach and precise anatomical

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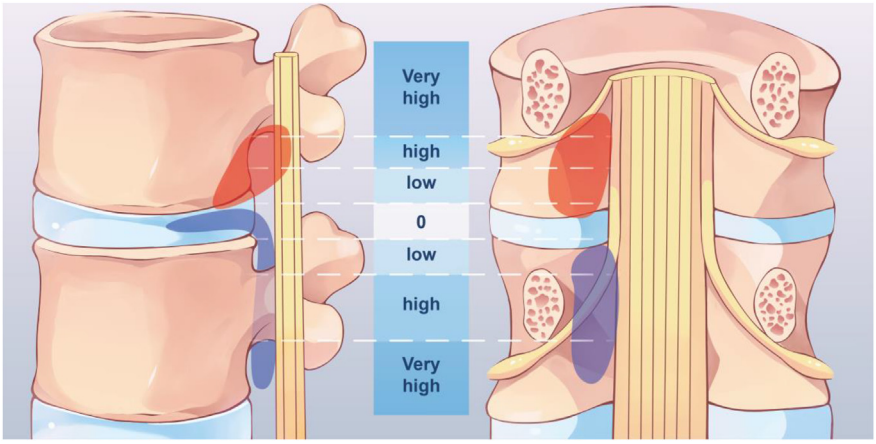

Figure 1. The schematic drawing of very highly up (shown in red) or down (shown in blue) migrated disc herniation.

matching of the fluoroscopic view [8, 9]. Recently, some surgeons have proposed various modified approaches and techniques for VHMDH with TELD [10, 11]. However, most of these reported techniques are prudent at lower levels and there is no definitive agreement on the technical guidelines.

The present study reports the modified techniques for TELD using targeted puncture and foraminotomy for VHMDH and discuss the satisfactory improvement in clinical outcomes of the preliminary series, aiming at providing another option for surgeons to treat the most difficult migrated herniations, not only migrating downwards but also migrating upwards.

2. Methods

2.1. General information

The study was carried out with the approval of the Ethics Committee of Shanghai Sixth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine. No: 2021-KY-51(K). All patients signed informed consent forms. From January 2016 to December 2019, patients with identified VHMDH were admitted to our hospital and those for whom it was medically appropriate underwent TELD by the same surgeon, using targeted puncture and foraminotomy techniques. 63 patients with at least 24 months of follow-up were included in the study. Among these patients there were 39 males and 24 females with an average age of 41.6 (18–77). The pathology was located at L2/3 in 2 cases, L3/4 in 4 cases, L4/5 in 33 cases and L5/S1 in 24 cases. According to MRI, the fragments had migrated upwards in 18 cases and downwards in 45 cases. Baseline demographics, radiographic data and clinical outcomes were collected (Table 1).

Table 1. Clinical data of the 46 patients.

Category	Value
Total patients	63
Males/females	39/24
Age (years)	41.6 (18–77)
Involved segment	
L2/3	2
L3/4	4
L4/5	33
L5/S1	24
Migration	
Upward	18
Downward	45
Anesthesia	
General	2
Local	61
Puncture technique	
Direct needle	18
TOM shield	45
Foramen widening type	
Direct puncture needle	18
TOM needle- partly bony removal	28
TOM needle- transpedicular	17
Operative time (minutes)	56.8 ± 10.6
Radiation time (seconds)	7.50 ± 1.78
Postoperative bed time (hours)	8.2 ± 4.4
Hospitalization time (days)	2.5 ± 0.8

2.2. Inclusion and exclusion criteria

Participants were included in the present study if they met the following eligibility criteria: 1) symptoms including low back or lower extremity pain, sensory changes or motor weakness, 2) single level VHMDH confirmed by MRI and computed tomography (CT) scans (Figures 2a–c; 3a-b; 4a), and 3) failure of conservative treatment lasting at least 8 weeks. The exclusion criteria were as follows: 1) imaging that did not correspond to clinical symptoms and signs, 2) Lumbar disc herniation (LDH) combined with other spinal disorders such as spondylolysis or instability, 3) multifocal lumbar pathology, 4) previous spinal surgery or postoperative recurrence, 5) basic diseases or comorbid conditions that precluded surgery, and 6) infection.

2.3. Surgical technique

To assure the intraoperative safety, 61 patients (96.8%) were performed under local anesthesia and conscious sedation, which enables surgeons to monitor patient status. The remaining 2 patients (3.2%) who underwent general anesthesia were strictly monitored with EMG. All patients were placed in the prone position on a radiolucent table for C-arm fluoroscopic guidance with genu-flexion and hip-flexion. Using anterior-posterior and lateral C-arm fluoroscopy, the surgical segment and entry point of the puncture needle were marked (Figure 2a–d). Generally, puncture was performed in the direction of the disc fragments 10–12 cm from the midline at an angle of approximately 30°–45° with

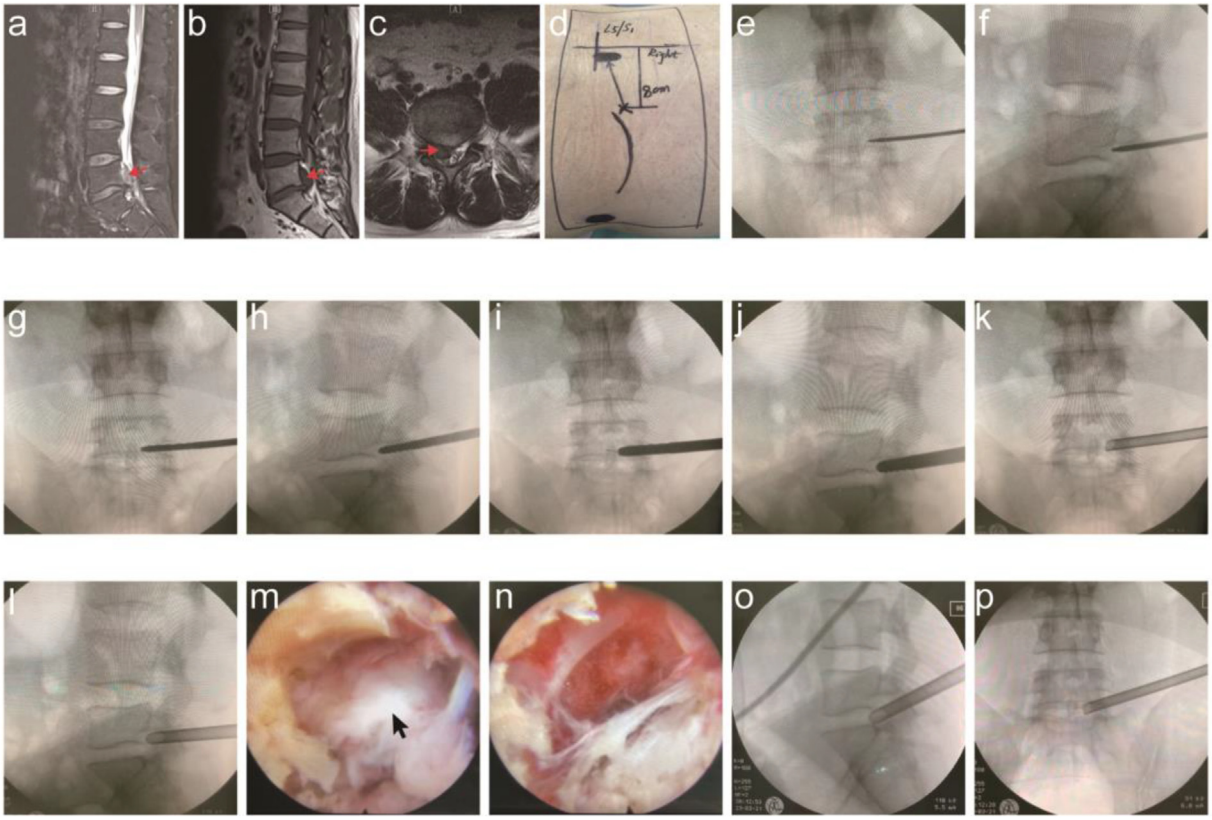

Figure 2. A 39-year-old man with highly migrated upward disc herniation from L5/S1 on the right side. A, B. Sagittal T1-and T2-weighted MRI showed that the sequestered fragment had undergone high migration from the L5/S1 segment in the cranial direction (red arrow). C. Axial T2-weighted MRI showed the sequestered fragment (red arrow) located on the right side in the spinal canal and compressed the dural sac and S1 nerve root. D. The sequestered fragment was marked on the skin on anterior-posterior (AP) and lateral views under the assistance of a C-arm fluoroscope. E, F. AP and lateral fluoroscopic view of the TOM shield needle, targeting the center of the sequestered fragment. G–J, AP and lateral fluoroscopic views showing the use of sequential bone drills to enlarge the intervertebral foramen for foraminotomy. K, L, When foraminotomy was completed, the working cannula was inserted, and an endoscope was placed. M, N: Large fragments (black arrow) were found on endoscopic view and were removed completely. O, P: The working cannula was maneuvered downward to the L5/S1 intervertebral space to remove the loosened and free nucleus pulposus in the disc.

the horizontal surface. In the L5/S1 segment, if the crista iliaca was high and could block access, the puncture point was shifted medially, and the puncture angle was increased [12].

When the needle tip reached the center of the disc fragments without any blocking from the facet or transverse process (Figures 3a–f; 5a–d), the needle was withdrawn and replaced by a guide wire. An approximately 0.7-cm skin incision was made around the guide wire, and a dilator was inserted into the facet joint. A sequence of bone drills from 4 mm to 8 mm was used to enlarge the intervertebral foramen for foraminotomy (Figure 3e).

If the puncture needle tip was blocked by the facet joints, and could not reach the center of the disc fragments, it was docked to the facet joints. The needle was pulled out and replaced by a guide wire. The skin incision was made, and a dilator was used as previously described. A Tom needle shield was inserted through the guide wire and the guide wire was pulled out. The Tom core was inserted, and Mallae was used to tap the Tom needle to reach the center of the disc (Figures 2e, f; 4b, c). The core of the Tom needle was pulled out, and a guide wire was inserted again. Then, bone drills were sequentially used to enlarge the bony access (Figures 2g–j; 4d–i), which connected with the foramen.

When the foraminotomy was accomplished, the working cannula was inserted, and an endoscope was placed (Figures 2k, l; 3f; 4j, k; 5e). Bleeding was controlled using a flexible-tip bipolar radiofrequency probe (Elliquence, LLC). Under endoscopic visualization, disk sequestration could be observed under the dural sac or nerve root (Figure 3g). Straight and bendable forceps were used to carefully remove the disk sequestration (Figures 2m, n; 4l). Then the working cannula was maneuvered upward or downward to the intervertebral space (Figure 2o, p). The tip of the bipolar radiofrequency probe was used to palpate for annular rupture, from which the loosened and free nucleus pulposus of the disc in the intervertebral space was removed. Successful decompression was accomplished when the nerve root was seen floating freely in the epidural space and when the patient reported that the preoperative symptoms were relieved (Figures 3h; 5f, g). Radiofrequency-thermal annuloplasty was typically performed at the end of the discectomy. The working cannula and endoscope were removed, and the wound was closed with a one-point subcutaneous suture.

2.4. Outcome parameters

To reduce the risk of bias toward positive results, two independent observers who were not involved in the surgery and patient care gathered and assessed all data. At baseline, the patients were required to complete the self-assessment questionnaires and provide demographic and clinical information. Clinical status was evaluated pre- and postoperatively using the visual analog scale (VAS), Oswestry Disability Index (ODI) and modified MacNab criteria. Lumbar MRI was reexamined 3 months postoperatively to evaluate disc resection and nerve root decompression. The operation time, intraoperative radiation times, postoperative bed rest time, length of hospitalization and surgery-related complications were also recorded. Patients were followed up 1 day, 3 months, 6 months, 1 year, and 2 years after surgery.

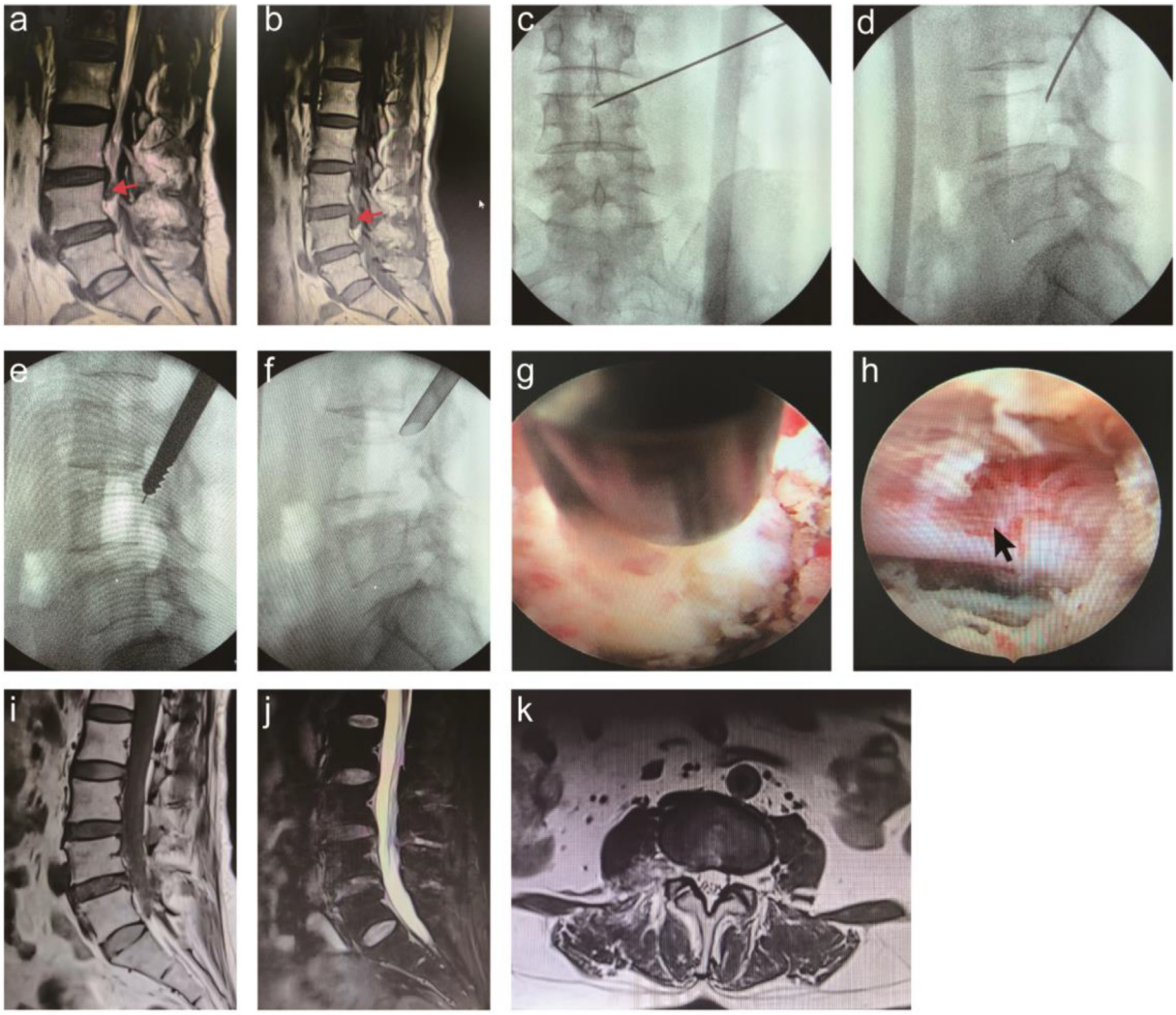

Figure 3. A, B: Sagittal T1-and T2-weighted MRI showed that the sequestered fragment had undergone a high degree of migration from L3/4 in the caudal direction (red arrow). C, D: The puncture needle was directly inserted and punched toward the disc fragments. E: Bone drill was used to enlarge the intervertebral foramen for foraminotomy. F: Working cannula was inserted toward the disc fragment directly. G: Under endoscopic visualization, disc sequestration could be visualized and removed. H: The nerve root (black arrow) was completely decompressed. I–K: Postoperative MRI showed that the disc fragments were removed completely.

2.5. Statistical analysis

The SPSS statistical program (version 27.0, SPSS Inc, Chicago, IL) was used for the statistical analysis. Continuous data are reported as the mean and SD or range, while categorical data are reported as numbers with accompanying percentages. Student's t test was used for statistical comparisons. P values less than 0.05 were considered statistically significant.

3. Results

Surgeries were performed successfully on all 63 patients without any changes in surgical modality. The average operative time was 56.8 ± 10.6 min (range 40–120 min). The C-arm X-ray radiation time was 7.50 ± 1.78 s, the postoperative bed rest duration was 8.2 ± 4.4 h (range, 3–24 h) and the hospitalization time was 2.5 ± 0.8 days (range 2–4 days). No surgery-related complications such as nerve root or equina caudal injury, dural tear, cerebrospinal fluid leakage, or wound infection were observed. A 56-year-old female patient, who underwent discectomy from the right side of L3/4, developed constant pain and numbness in the right leg for 3 months after surgery, which partially resolved with conservative treatment. A forty-one years old female patient showed recurrence of disc herniation at the same level, and was resolved by open surgery.

The VAS score decreased significantly, from 5.5 ± 1.3 preoperatively to 1.9 ± 1.30 ($p < 0.001$) 1 day postoperatively, and to 0.9 ± 0.8 ($p < 0.001$) at the final follow up. The ODI improved significantly, from 23.5 ± 3.2 preoperatively to 13.4 ± 3.0 ($p < 0.001$) 1 day postoperatively, and to 3.1 ± 1.2 ($p < 0.001$) at the final follow-up (Table 2). According to the modified MacNab criteria, 40 patients (63.5%) showed excellent results, 20 patients (31.7%) had good results, 2 patients (3.2%) had fine results; and 1 patient (1.6%) had bad results at the final follow-up.

Although no cases were lost to follow-up, MRI scans were obtained in only 38 cases (60.3%) because of the medical insurance policy. The scans showed no residual fragments in the lumbar canal and sufficient nerve root decompression (Figures 3i–k; 5h–j).

4. Discussion

To overcome the flaws of open surgery such as more disruptive muscle detachment and iatrogenic instability [4, 13], full-endoscopic lumbar discectomy was developed as an alternative minimally invasive procedure, and has become popular for the treatment of lumbar disc

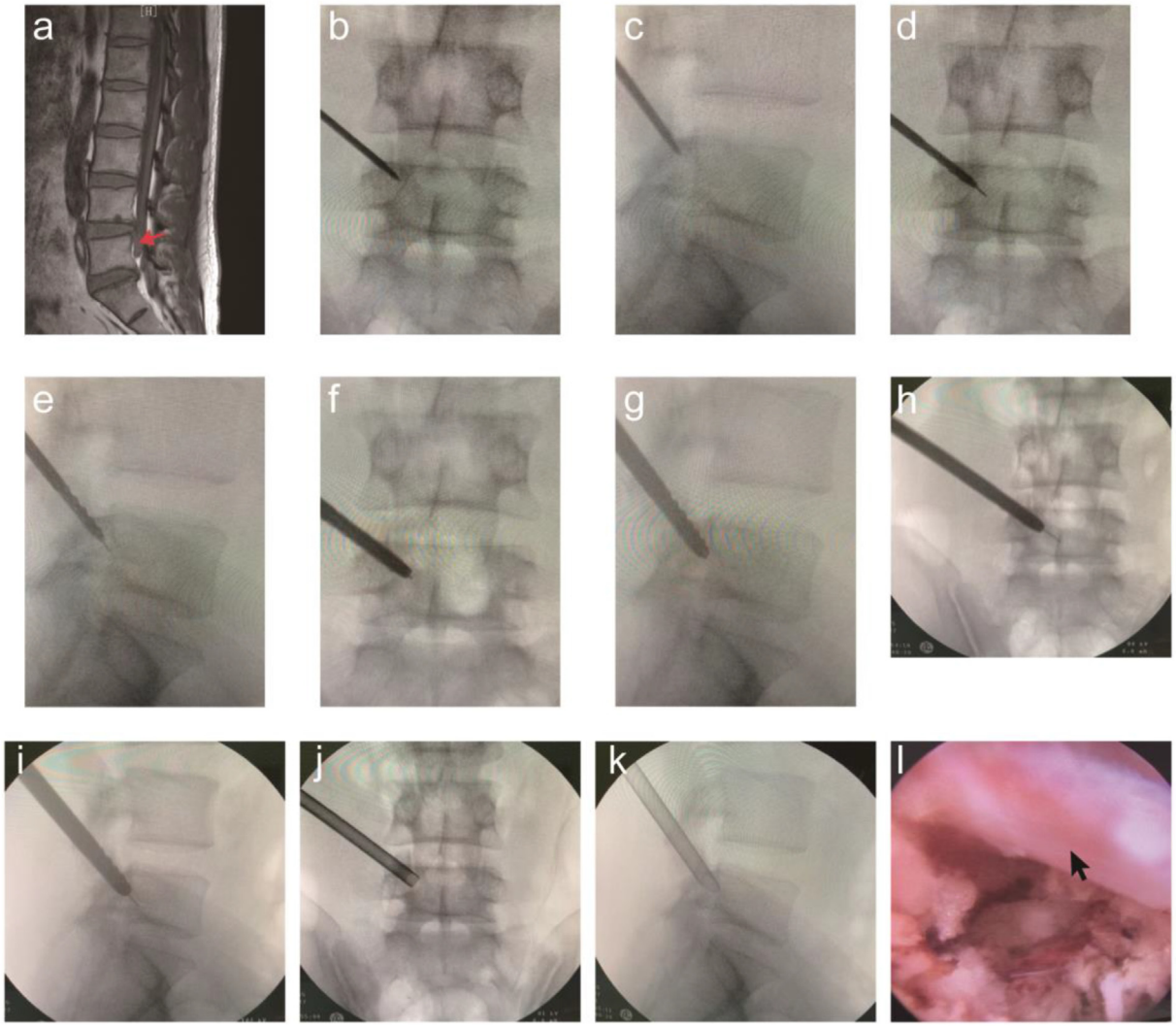

Figure 4. A: Sagittal T1-weighted MRI showed that the sequestered fragment had undergone a high degree of migration from the L4/5 segment in the caudal direction (red arrow). B, C: AP and lateral fluoroscopic view showed the TOM shield needle targeted to the sequestered fragment, penetrating both the ventral part of the superior articular process and the pedicle of L5. D–I: Foraminotomy was performed with sequential bone drills to enlarge the bony access. J, K: The working cannula was inserted, and an endoscope was placed for discectomy. L: The fragments were removed, and decompression was accomplished (black arrow).

herniation. With advanced surgical instruments and developing techniques, VHMDH is no longer excluded from endoscopic spine surgery (ESS) [4, 14]. Recently, a growing body of literature has reported that the removal of VHMDH with ESS, has a similar satisfactory outcome to open surgery.

Given the anatomic characteristics of the lumbar spine, IELD requires the removal of some portion of the lamina and facets to treat VHMDH, especially in the L3/4 or upper segments. Some modified translaminar osseous channel-assisted IELD techniques were introduced for selected VHMDH patients and satisfactory outcomes were obtained [15]. However, all these techniques of IELD were performed under general anesthesia [15, 16, 17]. But a recent study stated that 87% (137 out of 157) of patients had preoperative anxiety about spinal surgery and general anesthesia [18]. Among them, 26% of patients listed general anesthesia as the primary cause of anxiety [18]. Moreover, elderly patients or infirm individuals with comorbidities such as diabetes and cardiovascular diseases are at higher intraoperative risk under general anesthesia [5, 19, 20, 21].

In contrast, TELD, which is typically performed under local anesthesia and conscious sedation [22], enables surgeons to monitor patient status, thus avoiding the risks of anesthesia and nerve damage during surgery [23, 24]. Therefore, TELD has become increasingly popular and preferred for VHMDH. In the present study, the first 2 cases were treated surgically under general anesthesia; however, from the third case on, local anesthesia was used.

Anatomic limitations such as large facets overlapping the disc space, inferiorly directed transverse processes and narrow intertransverse space all hinder access to VHMDH in the lower lumbar segments with traditional TELD [25, 26]. Huang et al. found that 8.1% of patients with VHMDH at the L4/5 segment that underwent TELD required revision because of incomplete disc removal [17]. The key to performing TELD was ensuring the accurate location and optimized route of the working cannula to overcome anatomic limitations [19]. Therefore, several modified procedures have been described by researchers to surgically treat VHMDH.

Briefly, to obtain access to migrated fragments when the hard bony structure blocking, foraminoplasty with a drill or reamer to widen foraminal working window was necessary. Wu et al. reported 26 cases of VHMDH using the foraminoplasty endoscopic technique and obtained a 92.3% satisfactory rate [27]. In addition to the establishment of a widened foraminal working window, the choice of puncture point and direction also ultimately determines whether TELD treatment will be successful. On the other hand, the optimal puncture entry point and direction were determined by the location and position of the herniation.

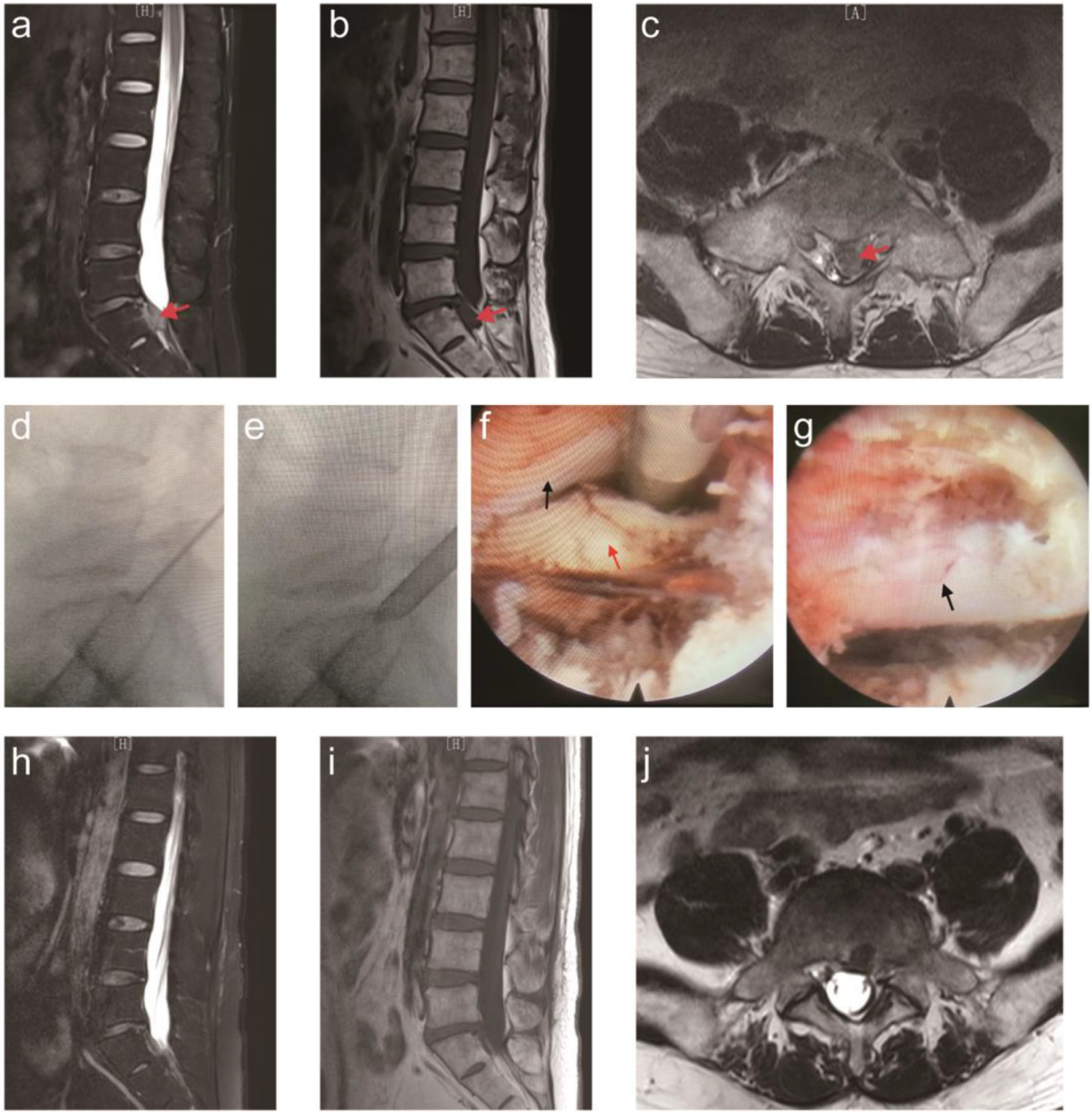

Figure 5. A 48-year-old man with VHMDH at the L5/S1 segment was successfully surgically treated. Preoperative T1-weighted (A), T2-weighted (B) and axial (C) MRI showed that large fragments had migrated downward from L5/S1 on the left side (red arrow). D: The puncture needle tip reached the center of disc fragment with any bony blocking. E: Working cannula was inserted toward the center of the disc fragment directly. F: Nerve root (black arrow) was compressed by the disc fragments (red arrow) on endoscopic view. G: Disc fragment was removed and the nerve (black arrow) was decompressed completely. H–J: Postoperative MRI showed that the sequestered fragments were removed completely.

Table 2. Pre- and postoperative VAS and ODI of the patients.

	Pre-op	1d Post-op	3m Post-op	Final follow-up
VAS	5.5 ± 1.3	1.9 ± 1.3*	1.3 ± 1.0**	0.9 ± 0.8***
ODI	23.5 ± 3.2	13.4 ± 3.0#	8.1 ± 2.2##	3.1 ± 1.2###

Values are mean ± SD.
* means $P < 0.001$, ** means $P < 0.001$, ***means $P < 0.001$.
# means $P < 0.001$, ## means $P < 0.001$, ### means $P < 0.001$.

Herein we modified TELD technique with targeted puncture and foraminotomy to make it more efficient and precise for VHMDH.

The skin puncture point was marked under the guidance of C-arm fluoroscopy according to the segment level and location of the disc fragments. Normally, puncture occurred 10–12 cm from the midline at an angle of approximately 30°–45°, which different from traditional puncture angle of 15–20° [28]. For L5/S1, the entry point moved medially with an increased puncture angle to avoid iliac crest obstruction and directly access the disc fragments. Unlike traditional puncture treatment of VHMDH, our technique did not require repeated radiation, which reduced the intraoperative radiation exposure of both patients and surgeons [12]. The advantages of standard open surgery over TELD are the direct approach and the reduced risk of disc residue [29]. Our modified TELD offered an equivalent direct and less destructive approach. Using this technique, both highly migrated fragments and herniations in the intervertebral space could be removed completely under continuous visualization. Theoretically, the technique we used was similar but distinct with the "outside-in" technique. Traditional outside-in TELD introduced a working cannula in the foramen and an enlargement of the foramen by using reamers [30]. In our TELD, the first critical step was

directly targeting the center of the fragment. If the puncture needle tip was blocked by the bony structures, and could not reach the center of the disc fragments. A Tom needle with sharp tip was used to create a passage reaching the center of the fragments, and selectively enlarging the foramen was another critical step. Normally, we remove the migrated disc fragments first. Then the working cannula and endoscope was maneuvered upward or downward to the intervertebral space (Figure 2p) to remove the loosened and degenerative disc, rather solely enlarging the foramen. The rationale behind our modified TELD with targeted puncture and foraminotomy is that it directly targets the center of the fragments and selectively enlarges the foramen, which is versatile in almost all types of VHMDH.

The main concern of this modified TELD technique was nerve root injury. However, the present study observed no surgery-related complications such nerve root injury or dura tear. To avoid nerve root injury, two notes should be emphasized. First, skin entry point was chosen medially to the midline with a bigger puncture angle. Second, local anesthesia with sedation was recommended to be used for the procedure. Another concern of this technique was postoperative instability due to aggressive foraminotomy. However, despite enlargement of the bony access connected with the foramen, the surgical technique proved to preserve spine stability after surgery. Instability did not occur at final follow-up.

Regarding the research methods, a major limitation of this study is the lack of a matched controlled group. Its retrospective design and the short term follow up also pose limitations. In the future, a prospective randomized controlled trial with a long term follow up should be performed to provide stronger evidence of the effectiveness of this technique.

5. Conclusion

In conclusion, TELD with targeted puncture and foraminotomy appears to be a safe and effective technique for VHMDH. With this technique, direct access to both disc fragments and the intervertebral space as well as complete decompression can be achieved. This modified technique would provide surgeons with another option for the treatment of VHMDH.

Declarations

Author contribution statement

Jun-Jie Shen: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Xin Wang: Contributed reagents, materials, analysis tools or data; Performed the experiments.

Bin Cai and Yuan-Yuan Chen: Analyzed and interpreted the data.

Guo-Wang Zhang: Contributed reagents, materials, analysis tools or data.

Jian-Guang Xu: Performed the experiments; Wrote the paper.

Xiao-Feng Lian: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgement

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